MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

SEPTEMBER•OCTOBER 1999

100th ANNIVERSARY SINCE 1899

The Computer of the Future

If Stan Williams of HP has his way, it will be a computer that assembles itself—in a beaker

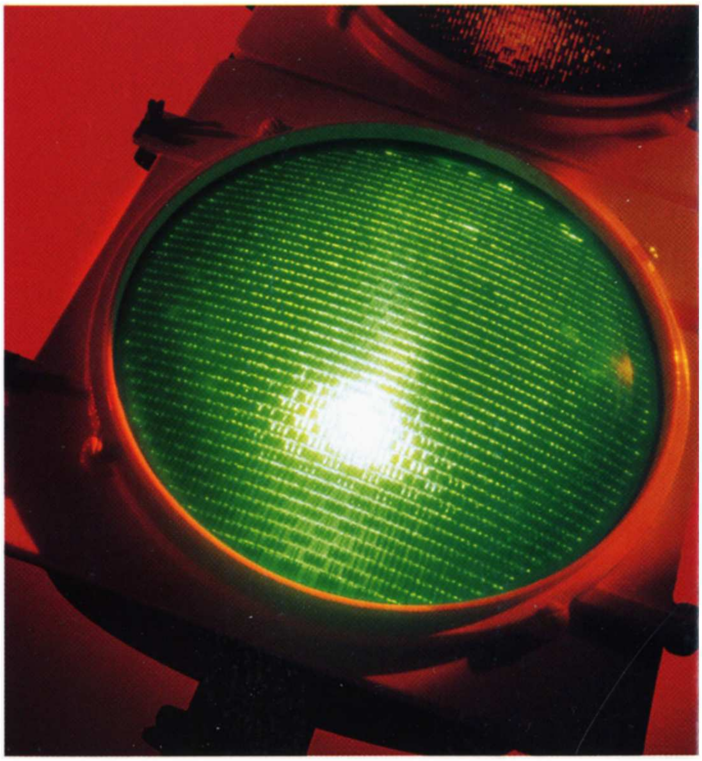
Coming Soon: Gridlock in the Air

Mining the Genome For New Drugs

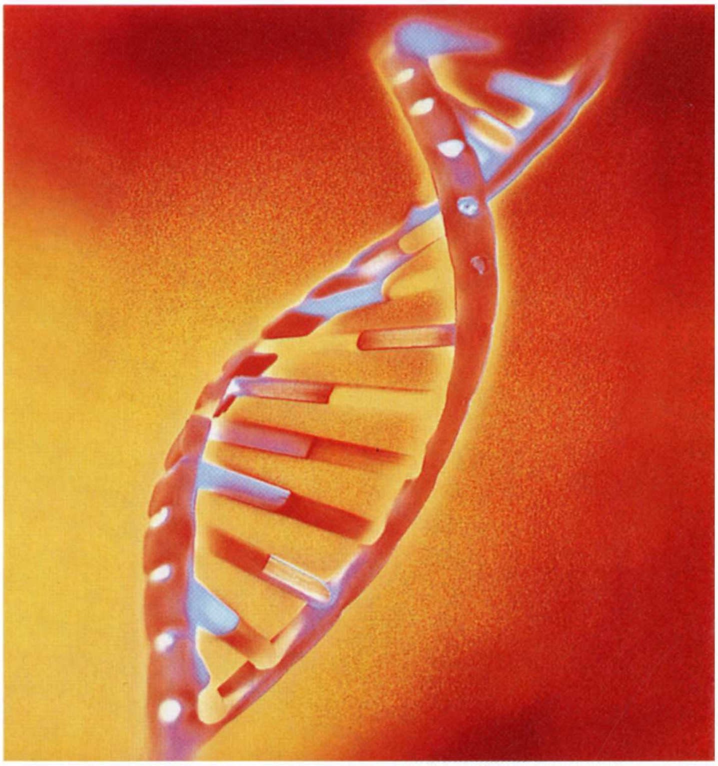
Micromachines—The Next Big Thing

U.S. $4.95 • CAN. $6.50

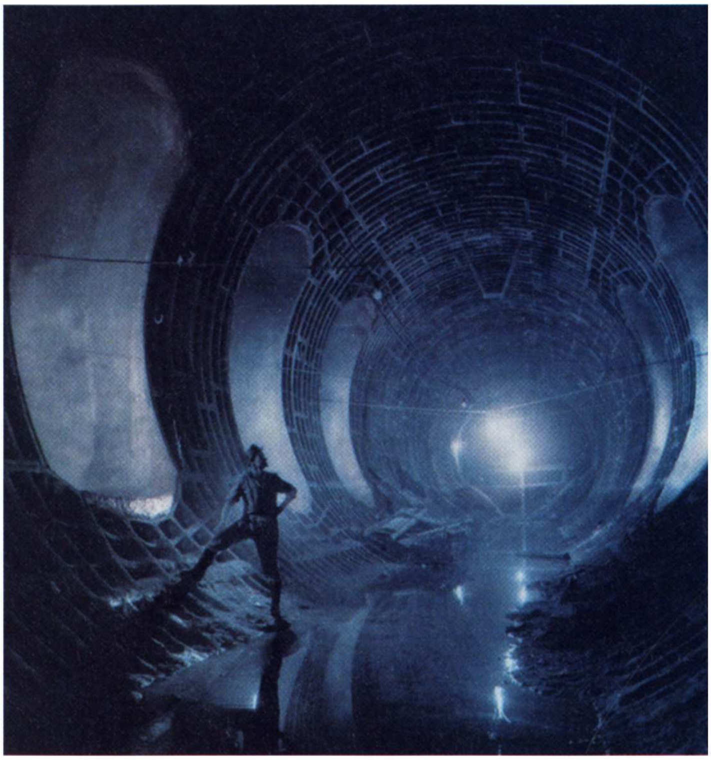
dreams made real.



dreams made real.



dreams made real.

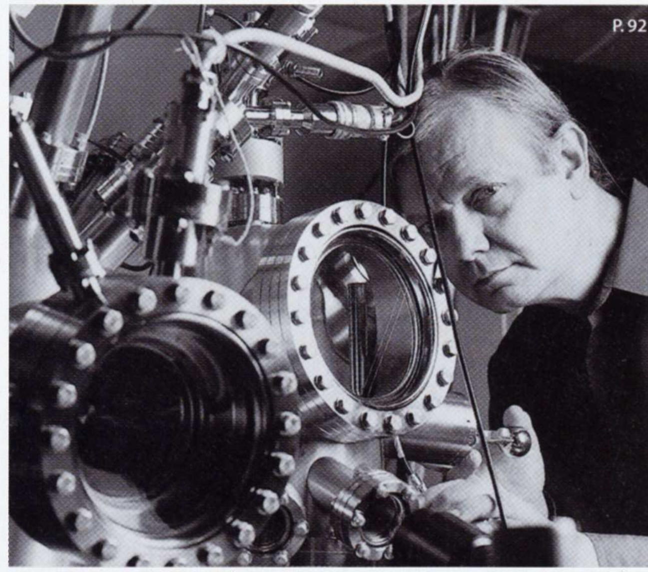


CONTENTS

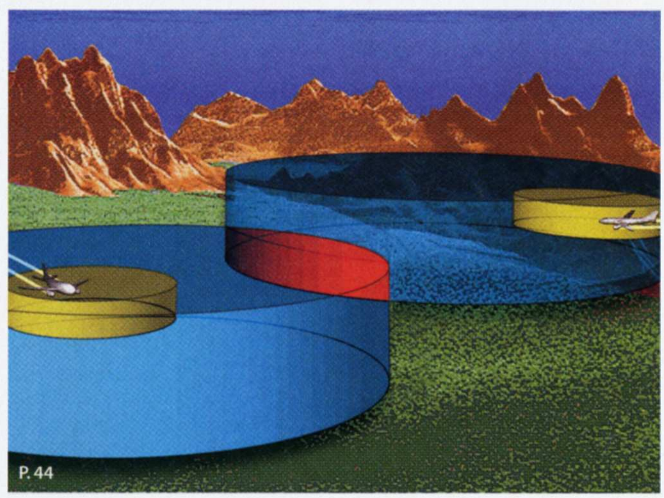
TECHNOLOGY REVIEW *September/October 1999*

VOLUME 102, NO. 5

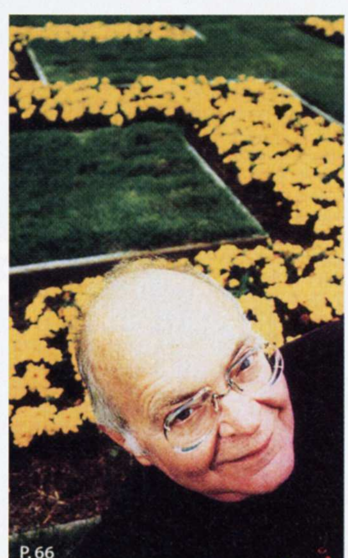
Features



P.92



P.44



P.66

P.84

Cover photograph by Anne Hamersky

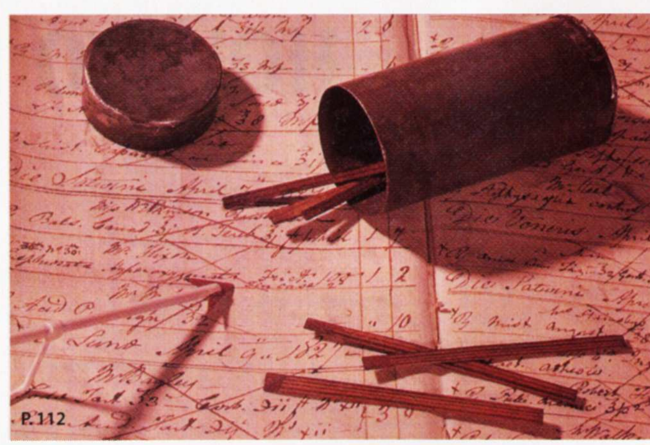
Departments

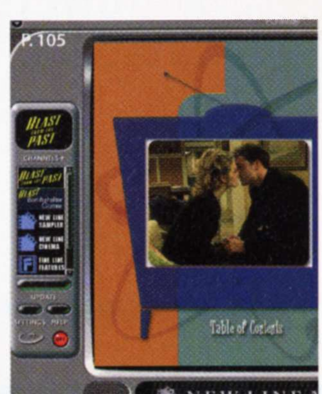

P. 26

Culture Zone

Columns


P.34


P.112



P.105


P.101

BIG BRAINS FOR RENT.

①

a.

FLEXON TECHNOLOGY

adapts the accordion-like corrugations of spacesuit joints to a ski boot to allow precision skiing and greater flexibility without distortion.

②

YOUR PRODUCT HERE.

Call us for a free search of NASA technology that may help your company's bottom line.

b.

③

c.

PIEZOELECTRIC ACTUATORS AND SENSORS

improve the quality and volume of ringers and speakers, and produce power to allow for smaller batteries.

④

d.

WATER PURIFICATION SYSTEMS

remove objectionable tastes and odors caused by chemicals in municipal water supplies.

⑤

e.

ADVANCED LUBRICANTS

produce an environmentally safe way to clean and protect fishing rods from rust and corrosion.

NASA has partnered with thousands of companies to help them develop all sorts of new products. You too can tap into the most cutting-edge technology ever developed. Visit our Web site or call the National Technology Transfer Center.

NASA

1-800/678-6882

A few other products that have benefited from NASA technology:

⑥ 

⑦ 

⑧ 

⑨ 

⑩ 

WWW.NASATECHNOLOGY.COM/MT 1-800-678-6882

INDEX

People and Organizations in Our Articles

PEOPLE

ORGANIZATIONS

Over the Wall

JUST A COUPLE OF YEARS AGO, STAN WILLIAMS WAS A PROFESSOR AT UCLA AND, well, he wasn't a household name. Now he's on his way there—at least in the households that pay close attention to emerging technologies. His story is instructive.

After 15 years in academia, Williams had begun to miss the sense of connection to the business world he had once felt at Bell Labs. At just about the same time, Hewlett-Packard, the venerable electronics giant, was having a career crisis of its own. Like most computer companies, HP had emphasized the D in R&D. But the most farseeing types at HP realized that its ability to thrive in the future would depend on its capacity to solve some fundamental problems—in particular, the looming physical barriers to cramming ever more circuitry onto silicon chips.

Enter Professor Williams. Forsaking tenure at a mighty university, he moved to HP to set up the company's first basic research lab. Now, after only four years at HP, Williams thinks he and his colleagues may have found a way over the wall that many experts believe silicon technology is going to hit in about 2010.

To find out what Williams' remarkable scheme is, you'll need to read the penetrating Q&A by Senior Editor David Rotman on page 92. But before you do, let me draw out a few lessons from this tale.

First, the membrane between basic research and commercialization of new technologies in the marketplace is extremely thin, and porous, and getting thinner all the time. Many creative university researchers have their hand in some form of commercial venture—a startup, a consulting firm, a big technology company. And, as Stan Williams' trek from Bell Labs to UCLA to HP shows, it has become easier for researchers to move back and forth between academia and the private sector, taking their intellectual capital with them.

The second lesson is that big discontinuities in technology require thinking way outside the box. Williams' ideas for the chemical assembly of computational circuits stem not from traditional chipmaking techniques but from chemistry and nanotechnology. His ability to see the possibilities for computing in distant fields no doubt owes something to his time at a university, where ideas from disparate areas of study are constantly jostling—in the faculty lounge, in the hallways, on the squash courts.

The third lesson comes directly from Williams himself, who tells Rotman that the end of silicon technology will create openings for small, nimble new companies. Many big chip makers, he argues, will be too heavily invested in existing technology to make a rapid changeover. He concedes that, despite his confidence in his own line of exotic research, the eventual winner in the race to succeed silicon will emerge from a vigorous competition among many approaches. But where will these new paradigms originate? Some will come from tiny startups, fueled by venture capital, enthusiasm and brilliant ideas, in many instances brought fresh from universities by graduate students and junior faculty. Others will take root at R&D labs of large companies that understand the value of investing in ideas.

And wherever those new technologies are coming from, we'll find them and bring them to you.

—John Benditt

MIT'S MAGAZINE OF INNOVATION
TECHNOLOGY REVIEW

SUBSCRIPTIONS: 800-877-5230, fax 815-734-5237, subscriptions@techreview.com; cost $30 per year, Canada residents add $6, other foreign countries add $12

QUESTIONS: 617-253-8292, subscriptions@techreview.com

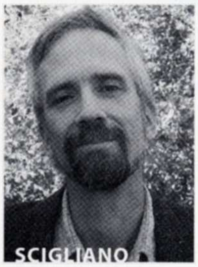
ADDRESS CHANGES: General 815-734-1116, address@techreview.com; MIT Records 617-253-8270

PERMISSIONS: 978-750-8400, http://www.copyright.com

REPRINTS: 717-560-2001, sales@rmsreprints.com or http://www.rmsreprints.com

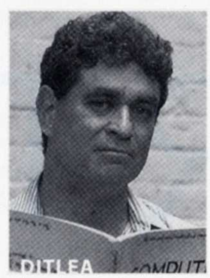
TECHNOLOGY REVIEW
201 Vassar St., W59-200
Cambridge, MA 02139
Tel: 617-253-8250
Fax: 617-258-8778
comments@techreview.com
www.techreview.com

Some of our best stories start when a curious detail catches a reporter's eye. That's just what happened when *TR* Senior Editor **David Rotman** first heard about Hewlett-Packard's R. Stanley Williams. Rotman was intrigued by HP's choice of a chemist (rather than a computer scientist or an electrical engineer) to run its basic-research lab. It turned out to be a great hunch: Williams' new chemical approach to building computer chips could come to fruition just as silicon reaches its limits. This beyond-silicon research strategy, described in the Q&A on p. 92, is shaping up to be one of 1999's biggest technology stories.



For a cogent account of a Byzantine clash between technology and bureaucracy, turn to p. 44 for **Eric Scigliano**'s article on free flight—a revolutionary idea for reforming the U.S. air traffic control system that has gotten tangled up in competing interests. Scigliano spent months retracing free flight's tortuous path through a maze of labs, government agencies, contractors, airlines, think tanks, unions and congressional hearings. A senior editor at the *Seattle Weekly*, Scigliano also freelances for publications such as *Slate*, *Outside* and *The New York Times.*

Imagine a reclusive genius so deeply engaged in work that his Web site warns he can't see visitors, doesn't do meetings and won't "undertake any new responsibilities of any kind." Now imagine interviewing him. We left that to *TR* contributing writer **Steve Ditlea**, who flew from New York to Palo Alto in search of Stanford professor emeritus Donald Knuth and the story behind his 40-year (and counting) labor of love: the encyclopedic *The Art of Computer Programming.* Ditlea came away with Knuth's Sisyphean tale (see p. 66) and one firm instruction: Destroy any record of the reclusive writer's telephone number.



Ditlea's Rolodex may have shrunk a little, but ours is growing as we continue to expand our circle of contributors. One talent new to *TR* this issue is **Meg Carter**, a London-based freelancer who writes about media, advertising and consumer trends for British dailies including *The Independent* and *The Financial Times.* Carter's journalistic specialties served her well during her visit to NCR's new Knowledge Lab, a corporate idea incubator whose plans for interactive soap operas and smart microwaves may be as much about public relations as they are about new technology. Her peek into the lab starts on p. 84.

While Carter was looking at the big picture, photographer **Felice Frankel** was using a microscope to capture amazingly small ones. An artist in residence and research scientist at MIT, Frankel opens a window onto the world of tiny turbines and diminutive diagnostics with her work illustrating writer **Ivan Amato**'s story on micromachines. Frankel's images from materials research have appeared on the covers of *Science* and *Nature*, and in *On the Surface of Things: Images of the Extraordinary in Science* (Chronicle Books, 1997). Before turning her lens on science seven years ago, Frankel spent nearly two decades as a landscape and architectural photographer learning how close-ups can tell big stories. "It's in the details where you can understand not only the larger design but also the brilliance and precision of the technology," she says. Thanks to a National Science Foundation grant, Frankel will be able to share her gift for visual communication—her handbook on making pictures in science and engineering is to be published by MIT Press in 2001.

MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

PUBLISHER AND CHIEF EXECUTIVE OFFICER
R. Bruce Journey
bjourney@mit.edu

ASSOCIATE PUBLISHER
Martha Connors
mconnors@mit.edu

ASSISTANT TO THE PUBLISHER/CEO
Elizabeth Surano

ADVERTISING

DIRECTOR OF ADVERTISING SALES
Paul Gillespie

ADVERTISING SERVICES COORDINATOR
Tanya Lauda

NEW ENGLAND/BOSTON: Paul Gillespie
617-253-8229
pgillespie@mit.edu

MID-ATLANTIC/NEW YORK: Yvonne Cooke
203-438-4977
y_cooke@msn.com

SOUTHEAST/ATLANTA: Tim Reis, Autumn Ison
770-993-7730
timreis@treisco.com
autumnison@treisco.com

SOUTHWEST/DALLAS: Steve Tierney
972-625-6688
steve.tierney@tierney.com

MICHIGAN/DETROIT: Kendra Knorp
248-546-9800
kknorp@detroitsales.com

MIDWEST/CHICAGO: Karen Gleason
Lisa Nelson
312-993-4111
moneymal@enteract.com

NORTHWEST/SAN FRANCISCO: Scott Morgan
415-912-2815
morgans@mit.edu

SOUTHERN CALIFORNIA/LA: Gregory Schipper
310-451-5655
gschipper@whiteassociates.com

EUROPE: Anthony Fitzgerald
David Wright
44-171-630-0978
afitzgerald@mediamedia.co.uk

BUSINESS DEVELOPMENT

DIRECTOR OF BUSINESS DEVELOPMENT
Lyn Chamberlin

CIRCULATION

CIRCULATION OPERATIONS MANAGER
Corrine L. Callahan

CIRCULATION PROMOTIONS MANAGER
Josh Getman

CIRCULATION AND MARKETING ASSISTANT
Sara Bulger

MARKETING

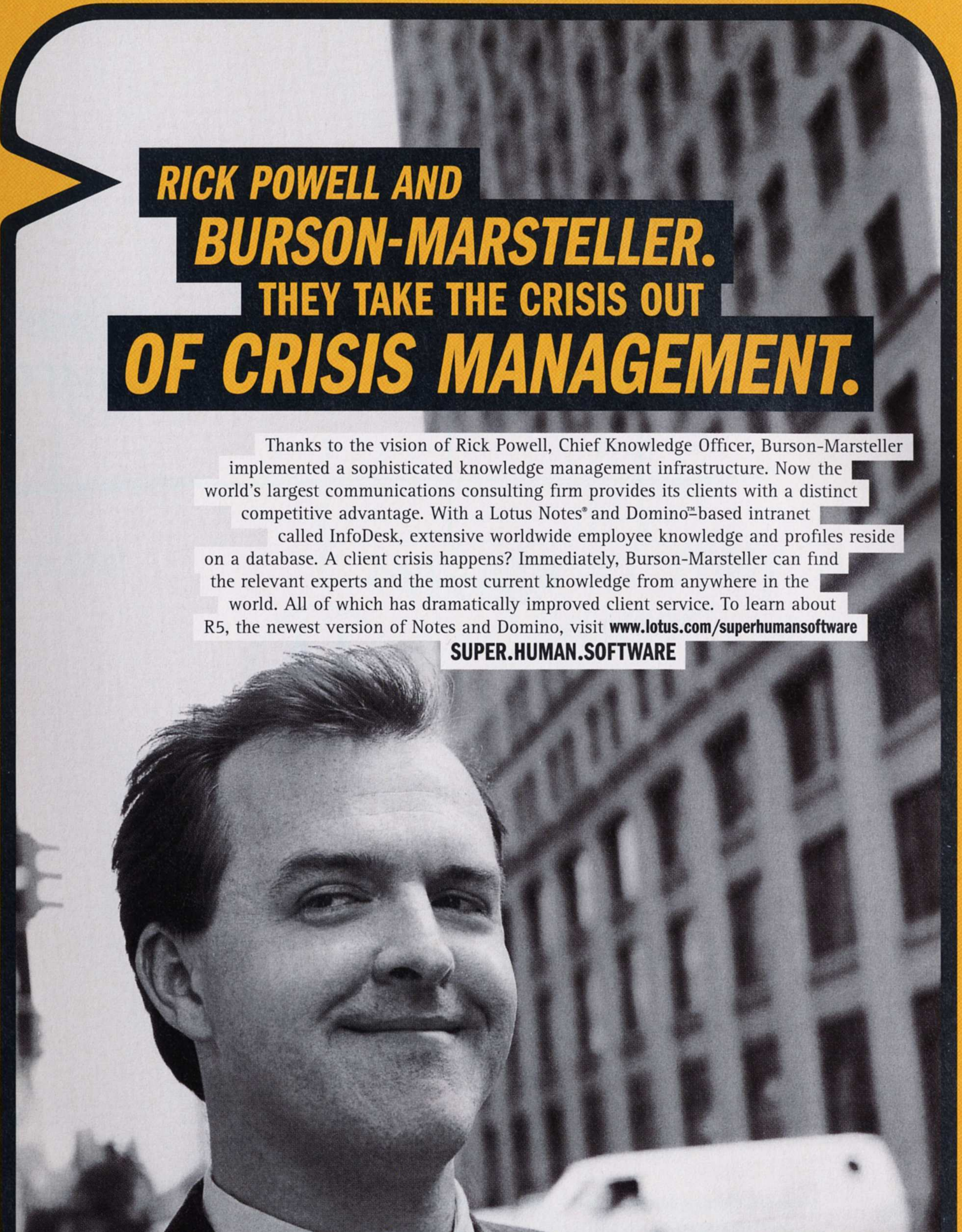
MARKETING COORDINATOR
Kristin Kelley

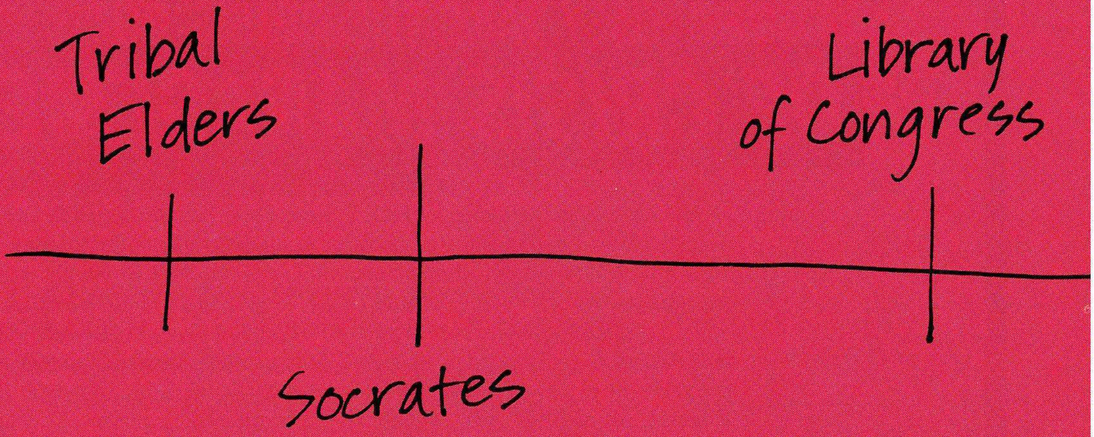
STAFF ACCOUNTANT
Letitia A. Trecartin

TR RELAUNCH FUND

MILLENNIAL PATRON
Robert M. Metcalfe

CENTENNIAL PATRONS
Steve Kirsch
DuWayne J. Peterson Jr.


RICK POWELL AND
BURSON-MARSTELLER.
THEY TAKE THE CRISIS OUT
OF CRISIS MANAGEMENT.
Thanks to the vision of Rick Powell, Chief Knowledge Officer, Burson-Marsteller implemented a sophisticated knowledge management infrastructure. Now the world's largest communications consulting firm provides its clients with a distinct competitive advantage. With a Lotus Notes® and Domino™-based intranet called InfoDesk, extensive worldwide employee knowledge and profiles reside on a database. A client crisis happens? Immediately, Burson-Marsteller can find the relevant experts and the most current knowledge from anywhere in the world. All of which has dramatically improved client service. To learn about R5, the newest version of Notes and Domino, visit www.lotus.com/superhumansoftware
SUPER.HUMAN.SOFTWARE
Lotus
An IBM Company



Tribal Elders
Socrates
Library of Congress

America's
smallest
Digital web Phone

Grapevine

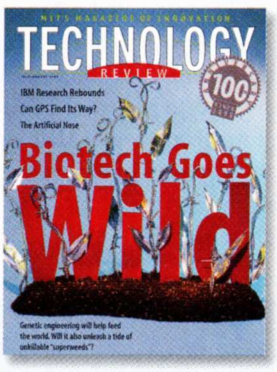
Internet-ready
Eyewear

Surf the Net from almost anywhere with Motorola's Timeport™ digital web phone. It's the smallest digital mini-browser phone in America. People will stare. And it's just the beginning of things to come.

"It seems accepted that the only way to feed the future masses is through biotechnology. I'm not so sure."

Agritech Angst

THE ARTICLE "BIOTECH GOES WILD" BY Charles C. Mann (*TR* July/August 1999) made little attempt to disguise its pro-biotechnology industry bias. The article minimizes specific human health and environmental concerns already voiced by ecologists and other scientists. Several potential harms from genetic engineering that have been noted by the Union of Concerned Scientists which were totally ignored by Mann include: new allergens in the food supply, transfer of antibiotic resistance, production of new toxins in plants, concentration of toxic metals, enhancement of the environment for toxic fungi, changes in herbicide use patterns, squandering of valuable pest susceptibility genes, poisoned wildlife, creation of new or worse viruses, and harms that are as yet unknown. The single sentence devoted to the danger transgenic corn pollen poses to nonpest monarch butterflies was totally inadequate.



GREGORY MARKHAM
Cleveland Heights, OH

"BIOTECH GOES WILD" MAKES A CASUAL attempt at exploring the controversies over agricultural biotechnology. But the article misleads readers by suggesting the biotechnology industry and government regulators recklessly introduced genetically modified crops into farming. Nothing could be further from the truth. Thousands of scientific studies, field trials and environmental risk assessments were conducted worldwide prior to commercial introduction of transgenic crops.

For example, the article incorrectly implies a May 1999 Cornell University study of *Bacillus thuringiensis* (Bt) corn's impact on monarch butterflies was the first assessment of its kind. Before Bt corn plants were commercially introduced, the U.S. Department of Agriculture (USDA) conducted environmental assessments that considered risks to insects beneficial to farming, other nontarget insects and endangered organisms, including certain species of butterflies. The USDA concluded in May 1995 the data showed no significant potential to adversely affect organisms in the environment other than the targeted pests, European corn borers.

An April 1997 scientific study in the journal *Environmental Entomology* that examined Bt corn pollen's impact on beetles, flower bugs and lacewings, all of which feed on corn borers as well as corn pollen, observed no detrimental effects on the beneficial insects and found more of them in Bt cornfields than in non-Bt cornfields.

Another example of misperceptions fostered by the article is the reference to a September 1998 study that purported to show transgenic Arabidopsis plants were 20 times more likely to outcross than mutant Arabidopsis plants. In fact, Arabidopsis is famous for its colonizing ability and its propensity to outcross. The study's scientists acknowledged they don't know if genetic modification accounted for their findings. If anything, the research confirmed what plant geneticists knew: Hybridization rates vary among plant varieties.

A critical aspect of the debate over transgenic crops is whether they pose a greater risk to the environment and food safety than plants genetically modified by conventional breeding. Study after study has shown they don't. In fact, the U.S. Food and Drug Administration (FDA) has stated recombinant DNA techniques, which introduce only one or a few genes into a crop, enable agricultural scientists to avoid a major difficulty of conventional cross-hybridization, which is the multiple introduction of uncharacterized genes with unpredictable impacts.

CARL B. FELDBAUM
President, Biotechnology Industry Organization
Washington, DC

IT SEEMS ACCEPTED AS GIVEN THAT THE only way to feed the future masses is through applying biotechnology practices. I'm not so sure. It's been known for some time that we are growing more than enough food for the planet population; it's the distribution network that's the problem. As long as food distribution is used as a political or military tool, it won't matter how much food is grown.

TERRY MOORE
Corvallis, OR

OUR SOCIETY AND THE WORLD HAVE BEEN able to evolve and prosper for centuries because of farmer adoption of new technology. New technology, the world's only unlimited resource, has the capacity to provide the necessary abundance to bolster future economic and political stability. Biotechnology, as one of these new technologies, provides economic potential in the race between population growth and food supply. Biotechnology has the potential to reduce pressure on fragile lands, reduce competition for limited resources and cut agricultural chemical use. It could reduce incentives to destroy more of the world's forests and at the same time increase food production and availability worldwide.

We believe the current system of federal regulation is fully adequate, now and for the future. The responsible agencies practice solid science, stay abreast of developments and have avoided temptations to cut corners. Rather than evidence of new risks, the record reveals that food inspection agencies have moved quickly to provide new protections. We as farmers need to prove to the public that we are good stewards of this technology and that benefits far outweigh the limitations.

While we believe that there is no need for additional federal regulation, there is a need for better coordination so new products can be brought to market in an

We welcome letters to the editor.

Write: *Technology Review*, Building W59, Cambridge, MA 02139. Fax: (617)258-8778. E-mail: <letters@techreview.com>. Please include your address, telephone number, and e-mail address. Letters may be edited for clarity and length.

expeditious manner. We support careful monitoring, fully funded by the Congress, and a vigorous research program maintained by public sector agencies and private firms. We believe this can be done safely without new regulation or new regulatory bodies.

DEAN KLECKNER
President, American Farm Bureau Federation
Washington, DC

CHARLES MANN IDENTIFIES A NUMBER of very troublesome side effects which may emerge from the widespread use of this particular biotechnology, but he completely ignores what one could argue is the most serious threat of all. Any kind of agricultural "green revolution" which is not accompanied by effective population control merely resets the limiting parameters at higher levels and enables countries with a large proportion of starving citizens to increase the absolute numbers of starving people. Mann declares that the "first" green revolution doubled the world grain harvests, "but global population numbers continue to rise, and researchers now must do it all over again." From what ethical or religious code does this moral obligation upon agricultural researchers spring? It is quite clear that a second green revolution unaccompanied by population control will only enlarge the corpus of misery.

What, then, is the moral course of action? I suggest that it is not only rather glib but ethically decrepit, as well, to assert that biological researchers "must do *it* all over again."

P.L. ABPLANALP
Professor of Anatomy, Illinois College of Optometry
Chicago, IL

No Free Rides

"HAS GPS LOST ITS WAY?" (*TR* JULY/AUGUST 1999) is complete as far as it goes, but I would like to see a follow-up article about the use of GPS outside the United States.

In Japan many taxicabs have GPS systems in them. In March I asked a Tokyo taxi driver about how he used his system. In his case it was not that he needed to know where he was—although I watched it show our progress through the streets and it was quite accurate. Instead, he used it to show traffic tie-ups. There are sensors over each lane on every block of major streets that obviously report to somewhere that sends out information to the in-car units, which then turn the streets on the map red where the traffic is not moving very fast. The driver can use the data without having to listen to a traffic reporter or read a road sign. This sort of system would be very useful in L.A. traffic. GPS's future lies in how many innovative ways it can be utilized.

CARL WALES
Fairbanks, AK

IN THE ARTICLE "HAS GPS LOST ITS WAY?" Claire Tristram writes that "purchasers of GPS receivers benefit from having a free signal: There are no monthly service fees for accessing GPS."

While that may be true in the literal sense, my last monthly paycheck had a federal income tax deduction of $858.02. That is a monthly fee for something. The Global Positioning System is taxpayer-funded and taxpayer-owned and to suggest that users are getting a free ride is incorrect.

JEFFREY FIELD
Loudon, NH

Big Blue Blues

IN YOUR EXCELLENT ARTICLE, "INTO THE Big Blue Yonder" (*TR* July/August 1999), giving some visibility to the unthinkable question (by nearly all academic scientists) of "How much science is enough?", John Armstrong, IBM's own former research vice president, says the finding that "less science will do" is deeply disturbing to the national scene. Indeed it is. And indeed the record at IBM, Bell Labs, Intel and Microsoft shows that much less of non-product-related science is enough. That question must now be asked about public research expenditures. If a corporation with strong line management cannot get value out of neutrino lifetimes, there is no way that this country's taxpayers (analogous to the corporation's shareholders) can benefit.

RUSTUM ROY
Evan Pugh Professor Emeritus
Penn State University
University Park, PA

WHILE SOME IN THE DOMINANT CLIQUE at IBM's Research Division certainly do believe that their future is bright, others have a different view. To make a monolithic division appear "vital to IBM's future success," that clique replaced a policy of pursuing scientific curiosity and technological opportunity with the pursuit of managerial ambition and corporate welfare. Skeptical scientists found their potential for success sharply rationed, even if their projects addressed a "vital" issue. For every top scientist absorbed happily into the management hierarchy—like Bernie Meyerson—there are now two who left the company and two others doing unproductive busywork.

For long-term success in research, an organization must do three things: give its staff members time, freedom and access to tools to make unexpected and unauthorized discoveries; allow the promotion and development of useful ideas, no matter what their origin; and direct the rewards for successful innovations to the individuals and organizations responsible in a way that encourages future productivity. In the late 1980s and early 1990s, IBM Research neglected to do all three. It is too soon to tell if the "new" regime will actually be able to perform differently.

MARC D. LEVENSON
Saratoga, CA

Better Brains?

MICHAEL DERTOUZOS CONDEMNS THE concept of brain implants ("Brain Implants: A Lousy Idea," *TR* July/August 1999). In doing so he avoids the inevitable: change to an unknown. Brain implants are only a new method to interface a human with a computer. It is what society will do with it that will change humanity in ways some do not want to accept. People will become less isolated. The Internet coupled with advances in neurocybernetics over the next 50 to 100 years will make the human race completely symbiotic with technology. Humans will then have the ability to converse with each other by thought alone. If such ideas go against someone's personal beliefs, then of course they will not participate.

DAVE TYPINSKI
High Springs, FL

Correction "Fresh Air for Mars" on page 21 of the July/August issue attributes to NASA engineers a system to extract oxygen from Martian air. In fact, this system was developed by K. R. Sridhar at the University of Arizona. NASA provided funding for development of the device.


CGW
PREMIER WINNER
1999
PC GAMER
EDITORS' CHOICE
COMPUTER GAMES AWARD WINNER
1998 SIMULATION
GAMESPOT
GAME OF THE YEAR
c|net
98 Award Winner
CNET Gamecenter
"European Air War's outstanding gameplay and wealth of features make it the current leader of the WWII simulation crop" -PC Gamer, 89%, Editor's Choice Award
"This World War II simulation captured the feeling of being in a living, unpredictable combat environment better than any other sim released this past year" -Computer Gaming World, 4 stars
"European Air War succeeds at providing the experience that makes arm-chair fighter pilots believe they're truly leaving their mundane surroundings behind" -Gamespot
RACKING UP
"No previous sim covers so many different weapons and so many tasks in detail... it's all here and it's all beautifully executed" -PC Gamer, 95%, Editor's Choice Award
"Falcon 4.0 is the deepest, most complex air combat sim yet... The campaign also creates the greatest sense of playing a small but important part of a huge battle" -PC Gamer
THE NEW BENCHMARK IN FLIGHT SIM TECHNOLOGY
FALCON
4.0
MICROPROSE
TEEN
"Thoughtful gameplay design and the effort to bring players a sense of the true fighter pilot's experience can be felt throughout the game" -Computer Games Strategy Plus


EUROPEAN
AIR WAR
20 FLYABLE PLANES!
MICROPROSE
EVERYONE
E
"European Air War combined huge dog fights, a great campaign system and realistic physics to make a game that was very hard to put down"
-IGN PC.com, Sim of the Year
"The care and attention to detail that went into every aspect of European Air War, from the hefty manual to the bomber nose art, represents a serious achievement"
-CNET GameCenter
THE KILLS!
"Bottom line: this sets the new standard in flight sims"
-Washington Post
"Falcon 4.0 is an incredibly detailed simulation that in many ways exceeds training systems in military use."
-Computer Gaming World
PC GAMER
ANNUAL AWARDS
BEST SIMULATION
1999
GAMERS CHOICE AWARD
GAMING
PREMIER
FINALIST
1999
Award of Excellence
www.FlightSim.com
HASBRO Interactive
MICROPROSE®
www.microprose.com
© 1999 Hasbro Interactive Inc. All Rights Reserved. MICROPROSE is a registered trademark of HASBRO INTERACTIVE or its affiliates. All other trademarks are property of their respective holders.

Magic Marker

Meeting hell: Someone—most likely your boss—is scribbling ideas, dates and numbers onto a whiteboard faster than you could ever copy them onto your notepad. Eventually you give up, hoping that somebody else has kept a better record than you have. If the room has an electronic whiteboard, of course, you're in luck—but such devices, which cost thousands of dollars, are far from being standard conference-room equipment.

Now comes a gadget—the mimio, from MIT spinoff Virtual Ink of Cambridge, Mass.—that captures the markings made on any ordinary whiteboard in real time and stores them on a PC for future perusal. The device consists of a portable sensor bar that attaches with suction cups to any flat writing surface—even a windowpane will do. A cable connects the bar to a PC. Ordinary markers are held in special ultrasound-emitting jackets; as the marker moves, the sensor tracks its motion by computing the ultrasound's travel time. The jackets even emit an infrared signal that indicates the marker's color.

WEBB CHAPPELL

Media Lab toy makes computers cuddly.

Playing Chicken

A child's imagination can turn a stuffed animal into a best friend. A new system developed at the MIT Media Lab promises to go even further, turning a plush chicken into a computer-control device.

Swamped! is a child-friendly approach to interactive video. As a story about a plucky chicken and a malicious raccoon unfolds on the computer screen, a child controls the chicken's action by manipulating its stuffed counterpart. The toy is filled with sensors: Flap its wings and the on-screen bird flies. Artificial intelligence enables raccoon responses, and unscripted hilarity follows. Bruce Blumberg, who heads the Media Lab's synthetic characters group, predicts these types of toys will be on the market within five years.

Curtains on All That Noise

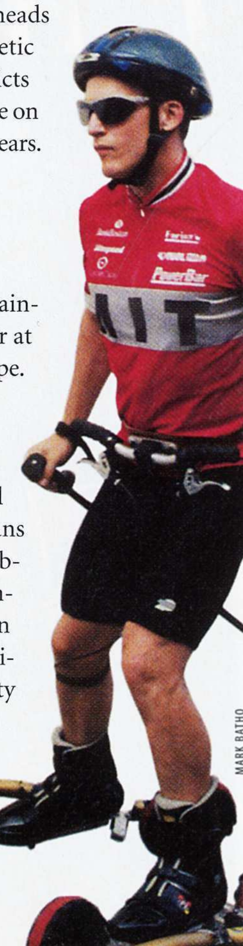
STANLEY LEARY/GEORGIA TECH

Measuring drapery decibels.

Hospitals and nursing homes can be noisy places, making it hard for people to sleep. To provide patients with some relief, researchers at Georgia Tech's aerospace and transportation laboratory have made high-tech curtains consisting of sheets of fabric that sandwich a noise-dampening plastic. In tests, the curtains reduced noise levels by 12 decibels—roughly a factor of 16.

The curtains are scheduled for further trials in actual nursing homes. Krishan Ahuja, head of the acoustics and aerodynamics branch at the lab, says the drapes could also be used to cut noise in factories and offices. By using different materials in the middle of the curtains (the group has tested everything from cardboard to metal), the Georgia Tech scientists can adjust the level of noise reduction. Ahuja hopes the quiet curtains will be ready for commercialization within a year.

Extreme Skates



MARK BATHO

What do you get when you cross skis, mountain-bike tires and in-line skates? A new sport—or at least that's what Jamie Page and Mark Batho hope. They founded Florence, Mass.-based Crosskate in April after inventing the hybrid skate.

The new skate incorporates 9-inch air-filled tires and a rigid boot on a sturdy metal frame. The front wheel turns when a rider leans and does not roll backward, easing uphill climbing. The back wheel has a bodyweight-controlled brake. Riders can use poles in a motion similar to either cross-country or downhill skiing, depending on terrain. Indeed, the similarity to skiing has drawn the attention of ski resorts eager to run lifts, open trails and draw summer clientele. The inventors hope to begin online marketing of Crosskates as early as next year.

Green Steel

Cars may soon be filling up with unleaded parts, thanks to a new form of steel developed at the University of Pittsburgh. Manufacturers use lead-containing steel to make many automotive and other parts—the soft lead makes the alloy easier to machine, but it's also toxic. So Pittsburgh researchers set out to find an environmentally friendly alternative.

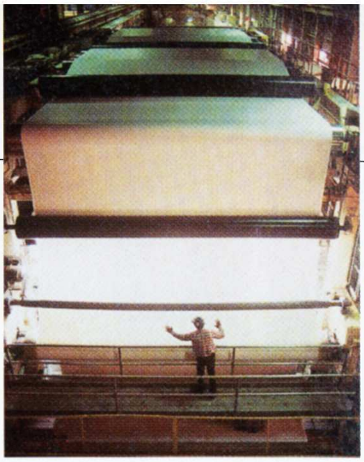
Materials science professors Anthony J. DeArdo and C. Isaac Garcia examined the lead's behavior at the molecular level. This insight helped them determine how tin could be used instead. The tin-containing steel can be machined at least as easily as the leaded alloy, says Bob Squier, president of Buffalo-based manufacturer Curtis Screw. In early manufacturing runs, says Squier, "It looks like it's doing the job." Squier's company is part of an international consortium organized to commercialize the new steel, and has already received an order from Ford for parts made of the alloy.

Twist Tube

The test tube has remained the same shape for centuries. Now, researchers at Norwind-Cortez, an Ypsilanti, Mich.-based biotechnology firm, have patented a version with a shape they believe improves upon the familiar form.

The new tube looks like its traditional counterpart with a bend at the open end. This and a flat side allow the vessel to rest horizontally without a rack. According to Norwind-Cortez president Milt Jackson, the bent tube reduces the risk of contamination, allows for more contact with air for cell culture experiments, and heats and cools more quickly. Licensing negotiations are under way.

Paper's Brighter Future



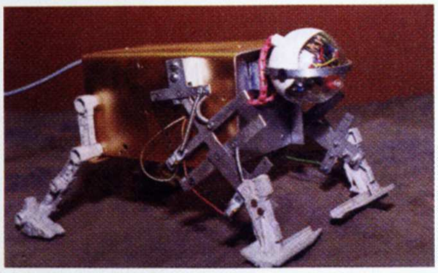
TOM TRACY/TONY STONE

Catalysts could cut industry's toxic waste.

The use of chlorine for bleaching and processing wood pulp to make paper is one of industry's dirtiest environmental practices, producing various highly toxic pollutants, including dioxin. Cleaner methods are available but chlorine has several big advantages; it's cheap and it works well. Now a chemist at Carnegie Mellon University (CMU) has developed a family of iron-based catalysts that could make one of the leading chlorine alternatives—hydrogen peroxide—more commercially attractive.

Small amounts of the catalysts, called TAML (tetraamido-macrocyclic ligand activators), greatly speed up the hydrogen peroxide bleaching process and allow it to take place at 50 C or even room temperature. What's more, the catalysts make hydrogen peroxide far more effective in "delignification," a key step for making high-quality paper. Terrence Collins, a chemist at CMU and developer of the technology, says industry is already testing the peroxide activators; he expects that the technology will be ready for commercial papermaking within three years.

Muscular Rover

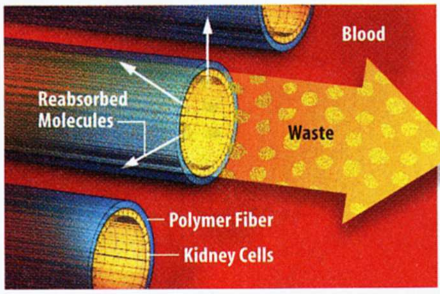


UNIVERSITY OF ARIZONA

Robots that explore the surface of Mars might someday resemble cats rather than carts. The Biomorphic Robot with Distributed Power (BiRoD), developed by the University of Arizona's Kumar Ramohalli and students, uses a series of battery-activated wires and springs to mimic the expansion and contraction of muscles while moving its legs. With no motor-and-gear systems to get jammed or clogged with dust, the BiRoD should be less prone to mechanical failure than robots like the six-wheeled Sojourner rover that rolled across the Martian terrain in 1997. Mechanical muscles can also store energy slowly and release it suddenly—"like a cat," Ramohalli says—to perform such tasks as crushing a rock, which would be impossible with a conventional rover. And the spring system is extremely compact: 25 BiRoDs could fit in the same space and have the same mass as Sojourner, giving future planetary missions added versatility and redundancy.

Artificial Renality

A dialysis filter can fill in for a kidney, separating body wastes from the blood. It works, but lost are some subtler jobs of kidney cells, such as reclaiming antioxidants and producing vitamin D. At the University of Michigan, tissue engineers have created a "bioartificial" kidney that looks to put cells, and their metabolic function, back in the picture. The team lined hollow polymer fibers with pig kidney cells and packed the fibers together in a cartridge. The device works in series with a dialysis machine: Wastes filtered out by dialysis run through the fibers while blood runs through the spaces between fibers, and the pig cells transport useful molecules across the permeable fiber walls and back into the blood. The researchers say that tests on dogs have been successful and human trials are planned, pending FDA approval. Ultimately, their ambition is to design an implantable bioartificial kidney that could replace dialysis altogether.



BETSY HAYES

Cell-lined fibers perform some kidney function.

Machine Marriage

Making a part and measuring its quality have long been two very separate operations. Often manufacturers send a finished part offsite to a facility that houses a coordinate measuring machine (CMM), which checks the part's conformity to specifications. For a company running a high-speed assembly line, the delay means wasted time.

To avoid this inefficiency, the folks at Tokyo-based measuring-tools manufacturer Mitutoyo have built a heavy-duty CMM called the Mach. The device is robust enough to be integrated with a machine tool to determine immediately if specifications are being met as a part is made. According to Bill Wilde, manager of marketing and research at MTI, Mitutoyo's U.S. subsidiary in Aurora, Ill., the Mach's measurement probe moves five times faster than that of a conventional CMM. Wilde says that MTI aims to offer the Mach commercially by mid-2000.

Want to think of an idea?

QUALCOMM

The conscious mind will probably take credit for this, too.

Introducing the pdQ™ smartphone.
But it's more than just a phone.
It utilizes the Palm Computing® platform.
It can access e-mail and the Internet,
and signal when you get a voice mail.*
The way we see it, your mind can
do some pretty amazing things.
Sometimes you simply need to get
out of its way. Go brain go.™

www.qualcomm.com USA 1-800-349-4188, Outside USA 1-858-651-4029

Privacy Is Not Doomed

THE CHINA AT THE ELECTRONIC-SPY AGENCY'S dining room was exquisite, as was the meal. Ron Rivest, inventor of the RSA approach to public cryptography, and I were having lunch with the National Security Agency's director, Bobby Inman. We were trying to impress on him that the forthcoming growth of the Information Marketplace would create severe privacy problems and the agency should extend the role of cryptography from ensuring secure communications within the U.S. government (and breakable ones outside it) to protecting the privacy of U.S. citizens and organizations, with approaches like RSA. The admiral didn't believe us—our claims of a widely interconnected civilian world in the '90s sounded like pie in the sky. Twenty-five years later, in April 1999, at the other extreme, *The Economist* proclaimed on its cover "The End of Privacy."

Under-reaction then! Over-reaction now!

No doubt, the technologies of information can be used to attack our privacy. But they can also be used to protect it. For example, if we agreed that everyone using the Internet did so under the RSA regime of creating and using their own public and private keys, we would end up with secure communications and files and the ability to digitally sign contracts and checks as effectively as we do now by hand. This high level of personal privacy would, however, preclude governments from legally tapping a suspect's private data and would also prevent anonymity—thereby angering Right and Left simultaneously. If we don't like this outcome, we have technologies on hand to establish nearly any desired blend of personal privacy, anonymity and governmental intervention.

Such cryptographic approaches would not stop companies with which you do business from selling personal data you give them, corrupting it, or tracking Web sites you frequent. Not to worry. There is technology around to handle these problems, as well: A scheme called P3P, developed by the World Wide Web Consortium, places software within your browser and in the Web sites of vendors. In a P3P personal profile, which you write once, you specify the personal information you are willing to give away along with what others are allowed to do with it. A similar script in the vendor's software identifies the personal information the vendor requires and its planned disposition. These two pieces of software "shake hands" prior to every business transaction and allow it to proceed only if both privacy declarations are satisfied. In a variation of this scheme, governments can introduce absolute privacy policies, by requiring, for example, a minimal level of privacy in the P3P profile of every citizen.

These examples accurately suggest that we have enough technology around to provide nearly any level of privacy we want. But what do we want? In the United States, consumers have become accustomed to treating privacy as a tradable commodity—we don't mind giving some of it away to get the goods and services we desire. Vendors are pushing for this approach because they are moving away from mass marketing to one-on-one selling, and are therefore anxious to build intimate knowledge of individual interests and habits.

To most non-Americans, however, privacy is not a tradable commodity but an inalienable right that must be guaranteed and protected, especially in the case of minors. The European Union, flexing its muscle, recently threatened to forbid its citizenry from doing electronic commerce with organizations (read U.S.) that do not meet a minimal threshold of absolute privacy guarantees. They have since backed down and gone to committee, as they and their American partners search for common ground. Last February at the World Economic Forum in Davos, Switzerland, a few industrialists tried to establish a voluntary code under which vendors would give you, upon request, all personal information they have on you, explain what they plan to do with it, and correct it if asked. Adoption of this code seemed a small and achievable step, but it failed to pass. The American vendors saw it as an expensive and difficult proposition to implement, and a potential leak of their marketing approaches to adversaries.

I almost fell out of my chair when the politicians asked the technologists to solve the privacy issue!

Clearly, we disagree about the kind of privacy we want. And we don't seem serious enough about reaching agreement—at that same meeting in Davos, I almost fell out of my chair when several world leaders asked the technologists present to "go figure out a solution to the privacy problems you brought upon us!" This abrogation of what should be a central responsibility of politicians and legislators must stop.

Let's not surrender our privacy to the big lie of technological inevitability. Let us, instead, augment the debates of privacy specialists, with a far broader discussion in the national legislatures of the industrial world and within international organizations, focusing on one issue—the kind of privacy people want. And let's be flexible—even though the United States sports most of the world's Web sites, we cannot expect six billion people to automatically adopt American constitutional amendments and habits. Reaching agreement on the kind of privacy people want nationally and internationally is an important and achievable goal at this stage of our history: We should be able to do it, as we have already done with passports, trade, airlines and cross-border justice. ◊

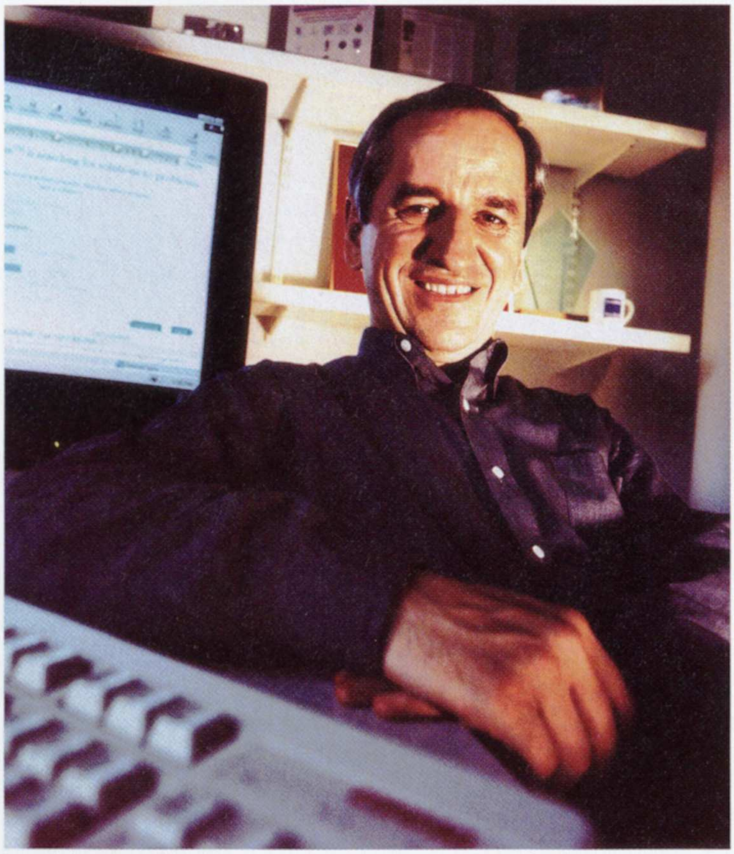
SOFTWARE

Genius Minus Perspiration

A Boston company aims to make invention automatic

THOMAS EDISON CALLED genius "one percent inspiration, 99 percent perspiration." Now Valery Tsourikov, a Russian-born entrepreneur, believes he has found a way to package the 99 percent and sell it as software.

Tsourikov's Boston-based company, aptly named "Invention Machine," has created and patented a program to speed the process of coming up with new technologies. "We understand how people invent," Tsourikov claims. "It's cause-effect analysis, backward reasoning and forward reasoning." The magic of genius, he says, comes from having a large knowledge base and knowing how to apply it.



MATT MCKEE

Your next bright idea could come from a computer program, says Valery Tsourikov.

To capture that magic in software, Tsourikov's program comes with more than 6,000 "cause and effect" processes and techniques, gathered from different fields of engineering. Each effect is integrated into a semantic network so that the computer knows when it can be applied and what it does. Much of the database stems from U.S. patents that have been painstakingly categorized. The company's newest program, called CoBrain, automates this data-gathering process as well. As a result, Tsourikov says, when companies buy Invention Machine, they can easily add their own proprietary processes and techniques to the database.

"It's much more than a really good encyclopedia," says Tom Carlisle, director of new technology at Phillips Petroleum. "It retrieves information in context." Carlisle's group is using Invention Machine to figure out ways of eliminating microscopic amounts of oxygen in natural-gas collection systems, which cause the equipment to corrode. "The problem-analysis section [of the software] has helped us clarify what the problem really is."

Tsourikov and four colleagues were granted a United States patent on Invention Machine's technology in May, but the seeds of the idea go back more than two decades. In 1975, Tsourikov was finishing a master's degree in computer science in Minsk. "AI [artificial intelligence] was very big at that time, but MIT, Stanford and CMU [Carnegie Mellon University] had already taken all of the good topics," he recalls. So, Tsourikov decided to create "a computer [program] that was able to invent things." Tsourikov worked nights on the IBM 360 computer at the Moscow Electrical Communications University, ultimately producing a program that could invent and test novel mathematical algorithms. In 1983 he contributed his software to the university's part of the international SETI (Search for Extra-Terrestrial Intelligence) project. Tsourikov's donation: 20,000 algorithms—invented by the computer—for distinguishing intelligent communications from background noise.

As any inventor knows, the key to success is being in the right place at the right time. Taking advantage of Gorbachev's economic reforms, which were opening Soviet markets in the early 1990s, Tsourikov started his own company in 1991 in Minsk to commercialize the technology. "In two years we had 800 major companies in Soviet industry running our program," says Tsourikov. In one notable success, engineers at an oil company were looking for a way to make oil flow faster through pipelines. Using Invention Machine's software, an engineer learned that he could decrease the viscosity of the oil by adding trace amounts of a polymer to the crude, the same way adding a polymer to blood can help it flow through constricted arteries.

Getting the business established in the United States proved to be a bigger challenge. In late 1991, Tsourikov flew to New York with five floppy disks in his briefcase.

"Every inventor in Russia knew that if you showed up with an invention in the U.S., you would be handed a blank check," he recalls sardonically. Unfortunately, such a check is only as good as the people writing it, and Tsourikov's dreams were delayed several years after he signed an exclusive license with a group of financially strapped investors.

Today, things are back on track: Invention Machine has 140 employees in Russia and 80 in the United States and Europe, with annual sales of more than $10 million. Whether Edison would be proud is a different question. "I love what they are doing," says Jane Linder, associate director of Andersen Consulting's Institute for Strategic Change. But Linder says some engineers, especially older ones, are less enthusiastic. She recalls one company where the engineers were hostile to Invention Machine's presentation. "These were leading, very creative people, who saw the potential of the technology to put into the hands of ordinary engineers, or younger ones who hadn't made their reputations, the ability to do things that would surpass these folks—and they didn't want it."

—Simson Garfinkel

RESTORATIONS

Virtual Archaeology

A good archaeologist needs brawn as well as brains to reconstruct a fragmented relic—pieces of objects such as stone statues can be heavy and must be manipulated carefully, since each move risks damage. Sometimes restorers even build external frames to hold fragments in position while other pieces are fitted, and there's always concern when the time comes to glue parts together that each is in the right place.

But computer-based imaging is changing how archaeology is done—possibly eliminating much of the heavy lifting. Researchers at the Museum of Terra Cotta Warriors and Horses in Xi'an, China, want to eliminate muscle and mishap from the restoration process by handling fragments in virtual space. There, the pieces could be endlessly arranged and rearranged and imperfections smoothed over. The team has an army of artifacts to work with: The scientists have been experimenting with ways to reconstruct digitally some of the 3,000 famous life-size terra cotta statues uncovered at the museum's site.

Virtual assembly of relic fragments is among the most recent installments in the application of ever-increasing computing power to archaeology. Says Alan Kalvin, research scientist at IBM's T.J. Watson Research Center in Yorktown Heights, N.Y., "Originally the computer applications were more statistical, but with computer prices coming down and performance improving, particularly in graphics, it's opened up the field for a lot of people." Jim Wiseman, director of the center for archaeology studies at Boston University, agrees that this is the next logical step: "This is just the kind of thing that would be useful for reconstruction of individual pieces."

To scan statue fragments into the computer, the Xi'an researchers use a laser range finder—a standard tool normally used for precisely measuring objects as diverse as manufactured parts or human bodies for clothing design—reconfigured to be portable and compact enough for an archaeological dig site. Equipped with a digital video camera and a laser, the device records each fragment's shape, surface colors and textures.

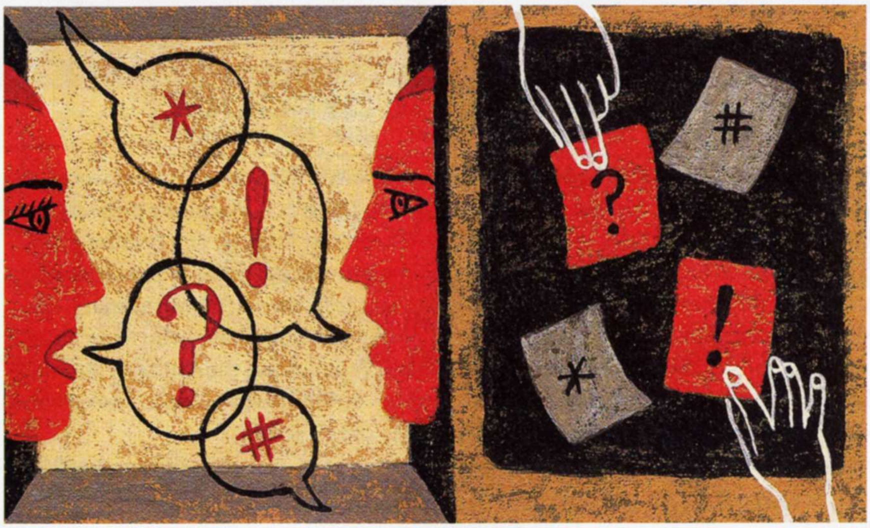
Far more challenging than getting the fragments into the virtual world, however, is manipulating them once they're there, says team leader Jiang Yu Zheng, associate professor of computer science and systems engineering at the Kyushu Institute of Technology in Fukuoka, Japan. The images contain so much data, according to Zheng, that the computer can only move them very slowly through virtual space. "If I reduce the data resolution," says Zheng, "the pieces will lose their value as art" and be more difficult to fit together accurately. Zheng and his team predict that further work on data handling, as well as faster computers, will speed the process up considerably.

JIANG YU ZHENG/KYUSHU INSTITUTE OF TECHNOLOGY

Three views of a virtually reconstructed terra cotta warrior.

Once archaeologists figure out how the virtual fragments of a relic fit together, they could use that information as a blueprint to reconstruct the object in actual space. But the ultimate value of such a system might be simply to leave the artifacts resting in peace. With an estimated 5,000 more statues still underground at the Xi'an site, museum staff imagine it may be enough to do the restorations virtually, without ever disturbing the remains.

—Deborah Kreuze



JAMES STEINBERG

INTERNET

Taking Back the Web

Are new services ways to share ideas, or graffiti?

When you're traipsing through endless corporate-image home pages, it's hard to remember that the folks who invented the Web wanted a tool to foster collaboration and community. Now a pair of free Web services, Third Voice and Gooey, are trying to restore that spirit to the medium. But the Web seems to be resisting this re-direction—in fact, these services have caused an uproar.

It doesn't take long to understand the controversy raised by Redwood City, Calif.-based Third Voice. Users of the company's software can treat the Web like a giant graffiti board. When they visit any site, they can post messages that appear to every visitor to the page using Third Voice. Some have taken to Third Voice like a graffiti artist to spray paint, and high-profile pages like Microsoft.com have become particularly easy targets.

Third Voice founder Eng-Siong Tan says, "The point of the Web is discussion and sharing of ideas." Third Voice, he adds, lets readers "take back a little bit of the Web."

But the people who own the sites where these notes appear aren't very enthusiastic. Third Voice represents an intrusion into a site owner's right to control content, says Char M. Green, director of legal research for a coalition of site owners called Say No To Third Voice. Green complains that Third Voice allows anyone to change the apparent content of the page. "It's vandalism," she says. Actually, the postings are stored on Third Voice's servers and overlaid on the target Web page—but Green dismisses this as a "technicality."

This summer, while the furor over Third Voice was raging, an Israeli company called Hypernix introduced Gooey—a Web-based chat service that seems to provide the open communication promised by Third Voice without invoking such angst. Gooey attempts to turn the Web into a gigantic party in which people exchange real-time messages with others visiting the same site at the same time. Each time you surf to a new site, you automatically join a new group of people who presumably share common interests. Hypernix posts a continuously updated list of the sites where Gooey users are congregating (in the early days of the service, however, the most active Gooey chat was at portal sites—not the sort of interest-sharing community that Gooey is designed to foster). About 46,000 people registered for Gooey in the first month after its launch, according to Hypernix CEO Shai Adler, who says that at any given time about 1,600 Gooey users are online.

Gooey has kicked up less of a ruckus than Third Voice. One reason: Gooey chat evaporates from a site once the users log off. Also, unlike Third Voice notes, Gooey chat occupies a separate, unobtrusive window. Moreover, real-time chat is becoming increasingly popular, and Gooey makes chat easily accessible at every Web site. Linking chat to a Web page that contains honest-to-goodness content may yield online exchanges with more depth than the inanity of many chat rooms.

Millions of Internet users have come to expect the Internet to serve up information. Now we will see if these legions of mouse potatoes are ready to turn the World Wide Brochure into a salon.

—Herb Brody

PLANT BIOTECH

40 Acres and an Antibody

A handful of companies have begun human tests of medicines grown in genetically engineered corn, potatoes, and even tobacco plants. Promising prospects include antibodies to fight cancer or infection. Antibodies can be grown in animals or cell culture, but "plantibodies" are cheaper, and don't risk spreading animal diseases to humans.

COMPANY	LOCATION	PLANT	PRODUCT	STATUS
Axis Genetics	Cambridge, UK	Potato	Edible hepatitis-B and diarrhea vaccines	phase I
Biosource Technologies	Vacaville, Calif.	Tobacco	Antibody vaccine for non-Hodgkin's B-cell lymphoma	preclinical
EPIcyte (with ReProtect)	San Diego, Calif.	Corn	Antibodies to prevent sexually transmitted diseases	preclinical
Planet Biotechnology	Mountain View, Calif.	Tobacco	Antibody to fight cavity-causing bacteria	phase II
ProdiGene	College Station, Texas	Corn	Hepatitis B vaccine	preclinical

SPACE EXPLORATION

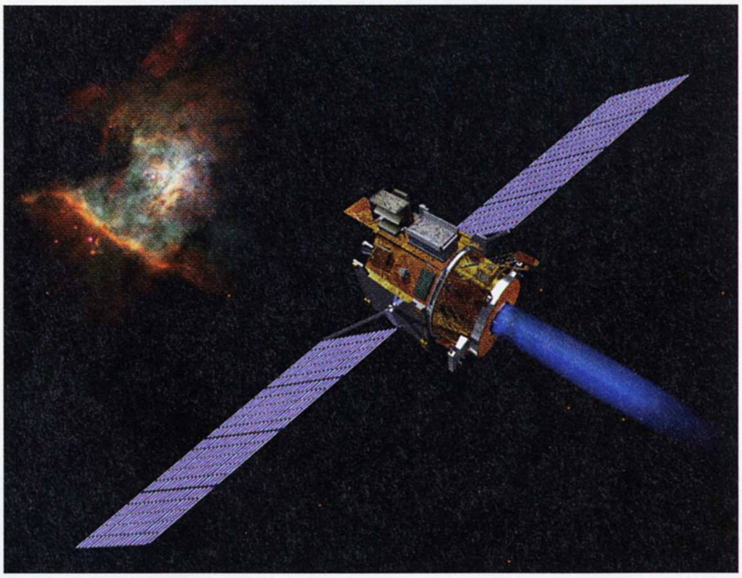
E.T.—Don't Call Home

A spacecraft thinks for itself

NASA's FLEET OF ROBOTIC SPACECRAFT has generated volumes of data about the solar system over the past 40 years. Yet, for all the insights these unmanned missions have provided, the spacecrafts are pretty dumb. A recent experiment, though, could make the next generation of planetary explorers smarter, more versatile and less expensive.

Unmanned spacecraft typically require significant handholding from mission control. A series of detailed, low-level commands are created on the ground and sent to the craft, telling it precisely what to do and when to do it. Most spacecraft also have a limited ability to deal with problems; when computers notice a problem with a key system, they shut down nonessential systems and wait for instructions from Earth.

For 35 hours over the course of one week in May, however, NASA's Jet Propulsion Laboratory (JPL) handed over control of its Deep Space 1 spacecraft to Remote Agent, an onboard software package that uses artificial intelligence to control the spacecraft with little input from ground controllers. The Remote Agent requires only high-level commands, such as "take an image of this asteroid." The software takes these commands and generates a timeline of events necessary to complete them. That timeline is passed on to the "Smart Executive," which fleshes out the timeline with detailed commands, which are passed on to various subsystems. A third portion of Remote Agent, "Livingstone," monitors the health of the spacecraft; when it detects a problem with a spacecraft system, it works to fix the problem or work around it. Only if those efforts fail does the spacecraft call home.



NASA/JPL/CALTECH

NASA's Deep Space 1 used artificial intelligence to run part of its mission.

During the May test, Remote Agent was given a number of high-level tasks. Ground controllers also simulated problems ranging from a balky camera to a broken thruster. In each case the software handled matters on its own, despite a minor problem with the Remote Agent software that was solved within several days.

The quick fix showed Remote Agent's versatility. "If it hadn't been for Remote Agent's ability to do onboard planning, we would not have been able to complete the tests so quickly," says Pandu Nayak, deputy manager of the project.

The success is leading NASA to consider using software like Remote Agent on future missions, according to Doug Bernard, Remote Agent manager at JPL. "This technology will allow us to pursue solar system exploration missions that would have been considered too elaborate, too costly, or too dependent on teams of Earth-bound controllers," he says. **—Jeff Foust**

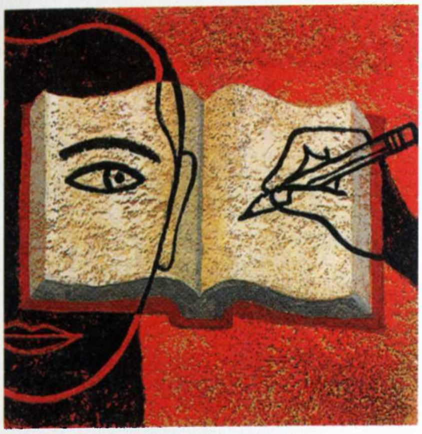
INTELLECTUAL PROPERTY

States Get an Edge in Patent Fights

State universities are big players in technology who often aggressively license research breakthroughs in fields such as biotechnology to companies, sometimes reaping millions in royalties. This complex intersection of public and private interests is rife with disputes over patent rights and inventions. And experts argue that a June ruling by the U.S. Supreme Court that citizens and companies can't sue states in federal court over intellectual property could give the universities a decided edge in such legal battles.

The decision has already had an impact on at least one high-profile patent dispute. According to Martin Simpson, counsel for the University of California (UC), the ruling "obliterated" a lawsuit against the school by Genentech, a San Francisco biotech company. Genentech had been trying to void a UC patent the university says covers recombinant human growth hormone, a drug that racked up $214 million in sales for Genentech last year. John Kidd, Genentech's lead litigator and a partner in the New York law firm of Rogers & Wells, says firms who want to sue a state will now have to take their case to state court, where there's no established forum for patent law. "I've got no place to sue," laments Kidd.

Companies say that's unfair because the Supreme Court decision leaves states free to sue them in federal court. In the Genentech/UC litigation, the university is countersuing Genentech for $1.2 billion, claiming the company stole key DNA code from a university lab. That case is unaffected by the Supreme Court decision. Given the court's ruling, it would seem that state universities can continue to dish out lawsuits, but no longer have to take them. **—Antonio Regalado**



JAMES STEINBERG

PUBLISHING

A New Openness

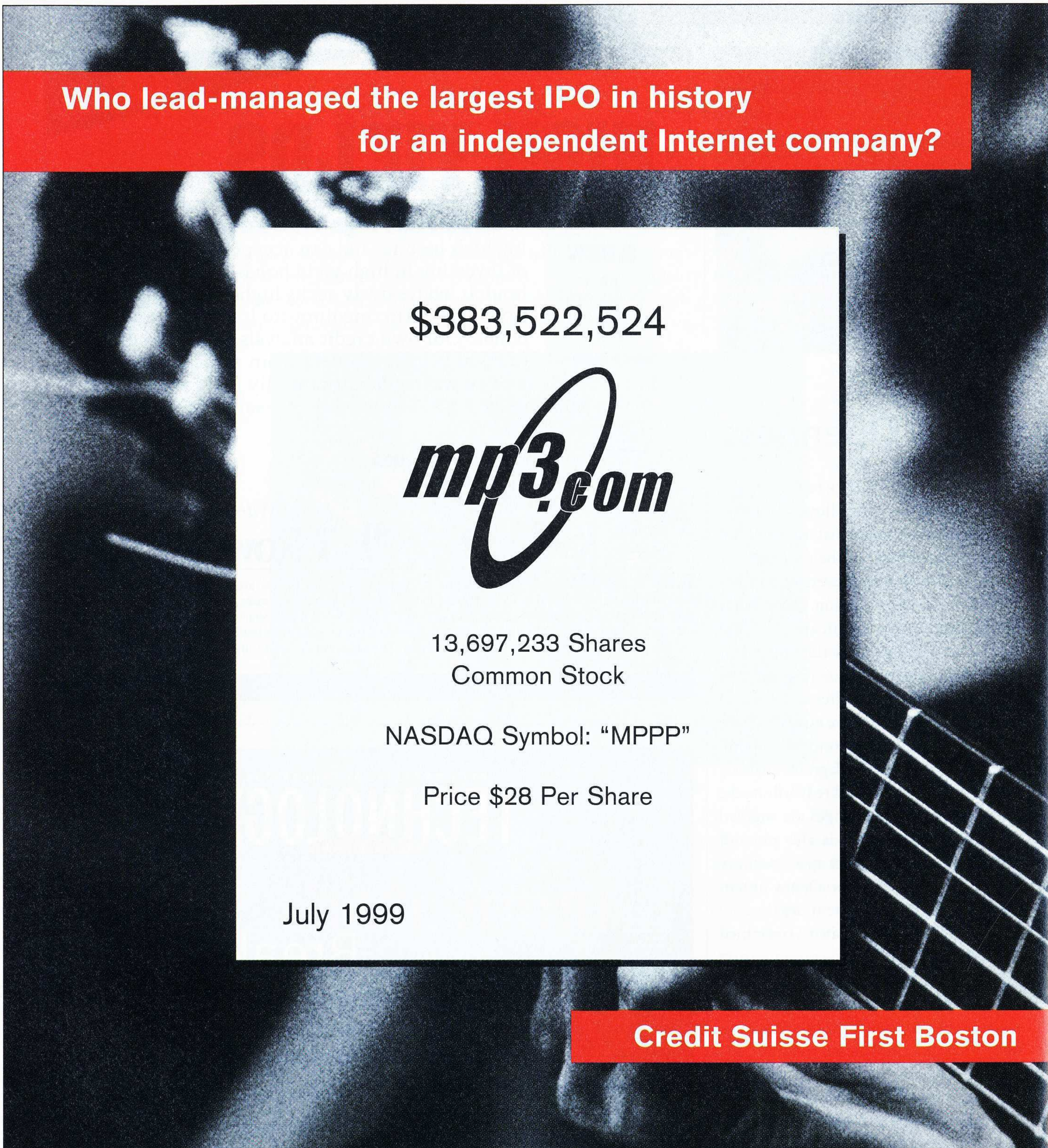
IT'S A PROBLEM MANY INTERNET USERS share: How do you allow successive modifications of online materials without losing the credibility of the original?

A Brigham Young University grad student thinks he has a solution. David Wiley modeled his open publication license (OPL) on the agreements that allow open-source programmers to constantly and collectively improve free software. (In fact, open-source software gurus Richard Stallman and Eric Raymond helped him draft the license.) The OPL grants anybody permission to modify and redistribute the materials, provided changes are marked and the resultant work is also put out under the license. Wiley set up a repository for all OPL works at the OpenContent Web site (www.opencontent.org).

As of July, the repository contained about 90 registered works, ranging from experimental art to university course materials. Wiley is working on a new OPL with an optional clause prohibiting commercial paper publication without the author's consent. This way, a work could benefit from online peer-review and peer-improvement while a hard-copy version's publisher would be protected from its competitors.

Mark Stone, an editor at O'Reilly & Associates, a California firm that is one of the leading publishers of material on programming and open-source software, says such crossover from the free-content community to the for-profit realm would be most valuable when the ideas are new and changing fast. Or, as Stone puts it: "where mindshare is more important than marketshare."

—Brad Stenger



Want your IPO to capture the world's imagination? Talk to the investment bank that has lead-managed many of the largest, category-defining IPOs: Credit Suisse First Boston. Most recently, Credit Suisse First Boston lead-managed a record-breaking IPO for MP3.com, which is pioneering a revolutionary approach to the promotion and distribution of music, and whose website has grown into a premier online music destination. Credit Suisse First Boston's in-depth understanding of the Internet and experience in positioning first-of-a-kind companies enabled MP3.com to tap the public markets in record time. During the roadshow, Credit Suisse First Boston advised MP3.com on a strategic investment by Groupe Arnault, which agreed to purchase an aggregate of $150 million in advertising, promotion and marketing services from MP3.com over the next three years. The offering was priced at $28 per share, as compared with an original filing range of $9 to $11, and represents the largest IPO in history for an independent Internet company. This historic transaction is one more example of how Credit Suisse First Boston is helping its clients revolutionize their industries.

www.tech.csfb.com

CREDIT SUISSE | FIRST BOSTON
Technology Group

This announcement is neither an offer to sell nor a solicitation of an offer to buy any of these securities. The offering is made only by the prospec

G. PASCAL ZACHARY

Net? Nyet!

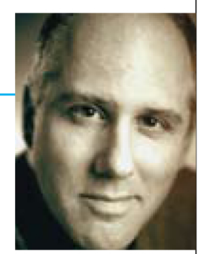
I CAN'T BEAR TO READ ANOTHER PREDICTION about the Internet altering human consciousness. I can't listen to another pooh-bah saying electronic commerce, via the Web, means a revolution in business. I can't tolerate the sight of another entrepreneur enriched by the sale of stock in a company without profits, revenues—or even a product.

I'm tired of hearing how e-commerce will conquer all. How the Internet and the Web will transform existing industries. I can't take it anymore. It's time for me to stand up for that silent majority of sensible skeptics that I know is out there. It's time to say what a lot of people are thinking privately but are too cowed to say in public.

Where is this nonsense coming from? Well, part of it is rooted in the American character. Americans like rooting for the underdog. They like it when champions get toppled.

This American ethos is wonderful, but it is also often wrong. If you liked the "Rocky" movie series, I'm sorry to disappoint you, but in real life the underdog usually loses.

Many more companies should be scrambling to forge a strategy to save themselves from their Web strategy.



My point is simple: The Web, if it triumphs, will largely reinforce existing business elites. E-commerce, regardless of the inroads it will make into traditional retailing and services, will sustain the advantages held by the leading corporations.

I am not saying "Web-World" is entirely a sham (although it's certainly partly that). I'm saying the Web can serve Wal-Mart and Merrill Lynch as well as Amazon.com or the 100th online peddler of garden tools. And in that contest, the rich will get richer.

I think the Web stampede is heading toward a cliff. When the herd goes over the edge, the financial carnage and psychological shock will be worse than anything wrought by Y2K. While many companies are still scrambling to forge a Web strategy, many more companies should be scrambling to forge *a strategy to save themselves from their Web strategy.*

What's driving the coming Web shakeout?

Let's start with the central premise of the online revolutionaries: the claim that doing business over the Web is cheaper than selling through traditional bricks-and-mortar. Nope. To be sure, the Web does certain things well. Amazon.com's order processing is terrific. Those little notes in your e-mail telling you the status of your order are helpful and endearing (until you decide to stop opening all e-mail from Amazon). But those books must still arrive the old-fashioned way. That's expensive and time-consuming and usually offsets the cost savings of buying electronically.

Now, of course, a growing number of people don't want to visit a bookstore, or even telephone a travel agent or a stockbroker. But this doesn't mean that stores and sales agents are irrelevant. They aren't. Consider bookselling again. Borders and Barnes & Noble are everywhere. What does Amazon.com do when bricks-and-mortar people personally deliver books to your home? What happens when the company assigns a person to me? An electronic agent is one thing; a human being is (still) something else again.

Take Dell. What made Dell Computer's revenues rise from nothing in 1984 to $18.2 billion last year? The key to Dell's success isn't the Web; it's that fabulous, cutting-edge, e-commerce gadget: the telephone. Customers phone in orders, setting off a chain reaction among suppliers that culminates in the assembly of a Dell personal computer. Where's the Web in this process? Hardly visible. As of late last year, just 5 percent of the company's daily sales come over the Web. Sure, this percentage will grow. But my point is that Dell will benefit from the Web because it's a leader already—it won't *become* a leader because of the Web.

What's important for entrepreneurs to realize is that chasing the ideal Web business isn't the path to success. What they need is a good business in the first place.

But wait, aren't those "good businesses" under attack by the Web? Aren't existing industry leaders usually muscled aside by upstarts because the giants are reluctant to destroy their old businesses in favor of the new?

Well, Amazon.com took a big lead in the electronic sale of books. But the big booksellers quickly responded. The story is the same in other industries, where leaders adopt Web-selling techniques even at the price of hurting their traditional sales and service networks. The effect is to blunt the advantage of the upstart and remind us again that the Web is a tool open to all—especially the rich and powerful.

A great example can be found in online music distribution. In Britain, EMI plans to make its entire back catalog of recorded music available via the Web. Customers will download tunes onto recordable CDs in music shops. EMI's partner in the deal is a small company, musicmaker.com, which sells customized discs over the Web. The problem is these discs must then be mailed to buyers, which takes at least two days. What musicmaker.com needs is stores, so buyers can get the discs instantly. EMI makes an ideal partner.

I'm bearish on businesses built solely on the Web. The coming years will see many of them wrecked. Failed virtual companies and worthless net stocks will mark the end of an era even as well-run real businesses follow the advantages of e-commerce wherever they may lead. ◊

Five years ago, the FAA set out to revolutionize air traffic control. Its comprehensive plan failed to attain airspeed—will an incremental approach fly before aerial gridlock sets in?

Delayed Take off

BY ERIC SCIGLIANO

Birds do it. Bees do it. Even Orville Wright did it. Why can't today's pilots do it too?

"It" is "free flight," an alluring notion thrust into official awareness by a passionate group of pilots and researchers in the mid-1990s. Free flight, these advocates argued, would transform aviation from, well, the ground up. The idea sounded simple and intuitive, and at the same time radical: Free pilots from the rigid, circuitous routes imposed by ground-based air traffic control, and let them choose the quickest and most fuel-efficient paths around wind and weather. New satellite, computer and communications technologies would keep aircraft from crashing into one another. Planes would fly faster, cheaper and even more safely, avoiding the gridlock that currently threatens the overloaded air traffic system.

Today, five years after Congress validated this vision and the Federal Aviation Administration (FAA) set out to realize it, free flight is still sitting on the runway. Air traffic is more congested, more delay-prone and scarcely any freer. "The whole idea of 'free flight' has kind of fizzled," says Heinz Erzberger of NASA's Ames Research Center, the lead scientist in the development of a more limited air traffic automation scheme now coming into use. The FAA and its constituents have retreated from a comprehensive free-flight agenda (what some critics call the "Big Bang" approach) to limited demonstration projects and incremental improvements.

For some, this retrenchment marks a welcome return to reality. For others, it is a temporary obstacle to clearance for takeoff. But for some of free flight's radical devotees, it's an unconscionable retreat from an urgent and eminently feasible mission, the latest in a string of costly botches and compromises by the FAA. And since there are no alternative proposals on the table for a substantial overhaul of the air traffic control system, some experts think we're on course for a nightmare in the sky.

PHOTOGRAPH BY VITO ALUIA

“We’re currently number ten for takeoff...”

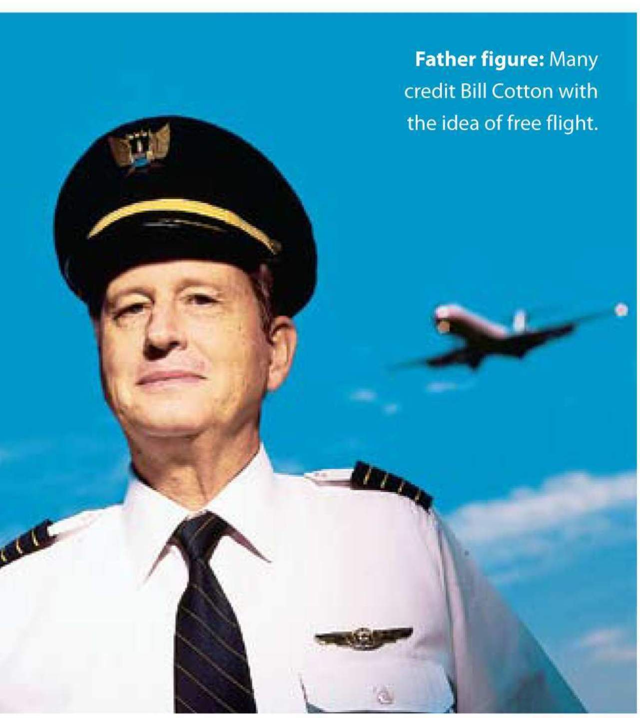
THOUGH OBSERVERS OF AIRLINE TRAFFIC don’t agree on much, they all concede that the existing system must be improved. With about 21,000 commercial flight departures each day, a number variously projected to grow by 2 percent to 5 percent a year, air planners have moved from lamenting congestion to invoking the dreaded “G” word.

“Gridlock is near,” the National Civil Aviation Review Commission intoned in a 1997 report titled, perhaps ironically, *A Consensus for Change.* “Traffic data and trends indicate that adding just a few minutes of delay to each airline flight in the United States will bring the aviation system to gridlock with dramatic negative impacts on the economy,” not to mention alarming “safety implications.” Delta Airlines, to name one example, has warned that even such relatively small additional delays will mean it can no longer function as a scheduled airline.

Meanwhile, despite repeated, costly modernization efforts, the outdated, overloaded air traffic control system is straining to keep up. Again and again, aircraft simply “disappear” from controllers’ radar screens; last year, Air Force One vanished twice. To compensate for such lapses, controllers must increase safety margins by boosting separation distances and holding planes back. That has kept the accident rate in U.S. commercial aviation stunningly low. But according to the man often called “the father of free flight,” pilot-turned-airline-manager William B. Cotton of United Airlines, that record comes at a price: “Safety has always been maintained at the expense of capacity and efficiency.”

Again and again, aircraft on controllers’ radar screens simply “disappear.” Last year, Air Force One vanished twice.

Although the system is straining to the breaking point, it is still remarkable that it works as well as it does, given the way it’s grown. For 40 years, functions, hardware and software have been mixed, matched, replaced and added in, forming a massive patchwork.



Father figure: Many credit Bill Cotton with the idea of free flight.

Today, controllers guide pilots verbally through each turn, climb, descent, acceleration and deceleration—from takeoff to landing—using only radar tracking and radio communications. Each controller in the FAA’s en-route centers monitors a sector that may be several hundred kilometers wide, with as many as 20 planes crossing at a time.

Limiting planes to preset routes across each sector helps the controller track and negotiate traffic. This is critical, because controllers must perform time-and-distance calculations in their heads. But preset routes add turns and miles, wasting fuel *(see “Shorter, Faster, Cheaper,” p. 50)*. And “handing off” flights from one controller’s sector to another’s creates opportunities for potentially dangerous errors, and for delay-inducing logjams when volumes climb (as they have recently with the surge in short-haul regional jet operations).

Even when this system was new, a few upstart innovators were thinking about making it better. Among the first was Cotton, now United Airlines’ Air Traffic and Flight Systems manager. In 1965, in his MIT master’s thesis, Cotton proposed that, instead of relying on ground instructions, planes could maintain flight separation through automatic air-to-air communication, with cockpit displays of the data they exchanged. At the time this scheme was a dream, since the technology to implement it didn’t exist. More than three decades later, these ideas would become essential elements of the FAA’s own free-flight concepts.

In the Zone

COTTON’S VISION, WHICH HE REFINED OVER the years, was built around the concept of safety “zones.” Each plane would maintain two electronic surveillance zones: an inner “protected zone” around itself, nestled in a larger “alert zone” spreading out in front *(see illustration inset, p. 50)*. To keep the protected zone inviolate, any overlap of alert zones would send a warning, prompting course corrections and restrictions.

An early step toward implementing the concept of Cotton’s zones was the Traffic Alert and Collision Avoidance System (TCAS), which grew out of collision-avoidance logic developed by Bendix in the 1950s. Required on all U.S. passenger aircraft since 1993, TCAS sends radio signals that, when returned by other planes’ transponders, inform the system of those planes’ approximate bearings and altitudes. It scans these data for prospective collisions and advises the pilot to climb, descend or stay steady.

Subsequently modified to prevent false alarms, TCAS has proved to be a lifesaving backup to traffic control and navigation. It has also been seen as a possible tool for realizing the tantalizing notion of free flight.

Indeed, it was TCAS that brought two of the key players in today’s free-flight debate together—before driving them apart. United pilot R. Michael Baiada had worked on navigation technologies as an

PHOTOGRAPHS BY JEFF SCIORTINO (LEFT), JOHN SOARES (RIGHT)

engineer at Bendix and on proto-free-flight efforts as a manager at a small airline. In 1987 he signed on at United under Cotton to help test TCAS.

Baiada, however, soon grew frustrated both with TCAS's limitations and with what he saw as Cotton's and United's failure to push hard enough for free flight. In 1993, he enlisted an outside analyst to determine the costs of inefficient air traffic control. United then undertook its own study, and NASA and the Air Transport Association soon followed with their own analyses. All put the annual costs at billions of dollars.

The persistent Baiada moved on to lobby Congress; despite their differences, Cotton concedes that Baiada was instrumental in persuading key members to convene hearings, in 1994, on free flight. The outcome: An industry/government task force under the RTCA (Radio Technical Commission for Aeronautics), the FAA's designated think tank, was deputed to draw the map to free flight, beginning with terms of reference drafted by Baiada.

The task force's breakthrough report, released in October 1995, established the official definition of free flight *(see "Free Flight Free-For-All," this page)*. And the RTCA group outlined a 46-point action plan—the so-called "Big Bang" approach—for achieving free flight by 2010. The FAA endorsed the report and designated a trial project called Halaska (subsequently renamed Free Flight 2000, then Flight 2000) as the proving ground for the technologies necessary to achieve the sort of self-separation envisioned in Cotton's zone model.

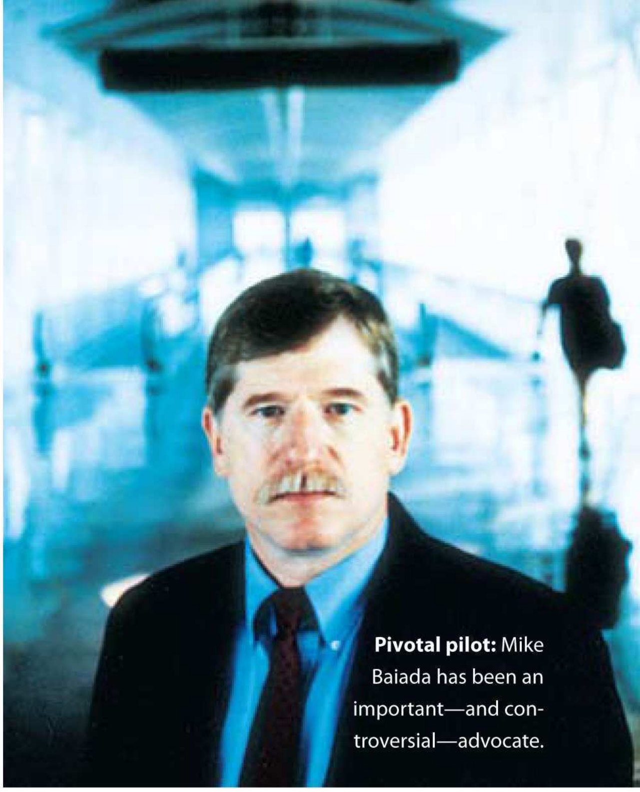
Thus conceived, the project included an ambitious suite of avionics (on-board instruments and systems) for communications, navigation and surveillance. Global Positioning System (GPS) receivers would provide satellite-derived location readings, boosted by ground-based wide- and local-area augmentation systems, that would be much more precise than conventional radar tracking.

Digitized radio communication between planes and with ground control, called "datalink," would ensure more speed, accuracy and reliability than voice-based communications.

New surveillance and broadcast systems would transmit planes' identification, positions, altitude, velocity and direction to controllers and other planes in the vicinity, and beam traffic, weather and other data from the ground to the cockpit. All this information, as well as controllers' digitally transmitted instructions, would be displayed for pilots on new cockpit screens.

Finally, a digital terrain database, linked to GPS, would let pilots "watch" the landforms below in order to avoid the nastily persistent form of crash called "controlled flight into terrain."

The project began with high hopes. Planners chose Hawaii and Alaska as test beds, because of their relative isolation and diverse mix of commercial and general-aviation flights. But troubling questions dogged the test. Only one of the main technologies—basic, unaugmented GPS—was in use. Furthermore, critics argued, introducing new avionics without changing the way air traffic is routed was like souping up the engine without connecting the drive train. "The pilots already have plenty of good equipment on board," laments NASA's Erzberger. "That's not the problem. Ground control is."



Pivotal pilot: Mike Baiada has been an important—and controversial—advocate.

Baiada's Bare Bones

AS THE OFFICIAL VERSION OF FREE FLIGHT lumbered toward takeoff, one of its champions—Baiada—was growing more and more impatient. The problem, he decided, was not too little technology, but too much reliance on new, unnecessary and unaffordable technologies.

Baiada argues vehemently that while GPS, datalink and other avionics can make flight more efficient, they aren't essential to free flight. And by making the move to free flight much more protracted, complicated and costly, they effectively keep it from happening.

By contrast, Baiada proposes a starkly heretical "minimalist" approach to free flight. All it takes, he argues, is adding two software capabilities to existing ground-based computer systems. One, called

Free Flight Free-For-All

One problem with implementing free flight just might be that nobody can agree on what the term means.

The FAA's "official" definition, drafted by a task force of the advisory group the RTCA: "A safe and efficient flight operating capability under instrument flight rules in which the operators have the freedom to select their path and speed in real time.... Any activity which removes restrictions represents a move toward free flight."

The National Association of Air Traffic Controllers has a different idea: "Unrestricted access to U.S. air space by all segments of aviation, ranging from the single engine two-seater plane to largest, mega-ton commercial and military aircraft."

Some make the economics more explicit. Free flight evangelist Mike Baiada defines it as: "The safe removal of air traffic control from the business equation, allowing airlines, operators and pilots the operational flexibility to meet their individual goals. [To be] accomplished by completely re-engineering the air traffic control system at no cost to the operators."

United Airlines air traffic and flight-systems manager Bill Cotton calls it simply, "anything that removes restrictions to flight."

Lucent Technologies
Bell Labs Innovations
600 Mountain Avenue
Murray Hill, NJ 07974
1-888-4-Lucent
www.lucent.com

We see the future of communications (and it's looking good).

Some will tell you the future of communications is all about one kind of network.

We see a bigger picture than that.

(We're optimists.)

The future is about the Internet, data, voice, optical and wireless working together.

With unlimited potential.

We have the vision and know-how to give you the network you need.

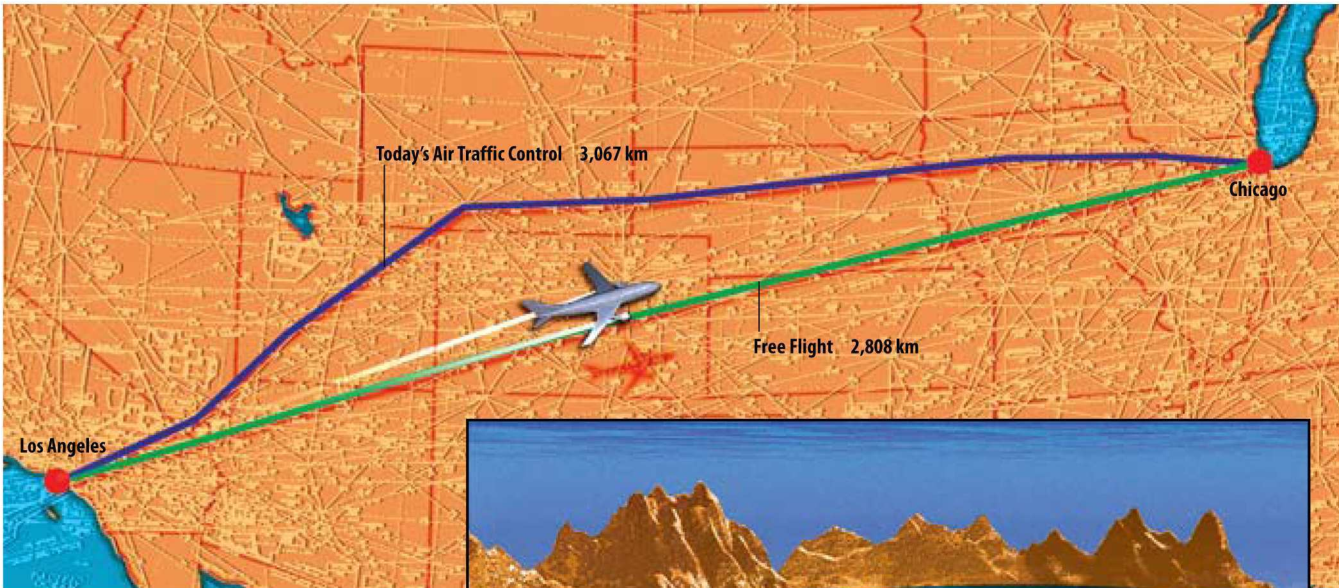
Along with the software and service to make it all work.

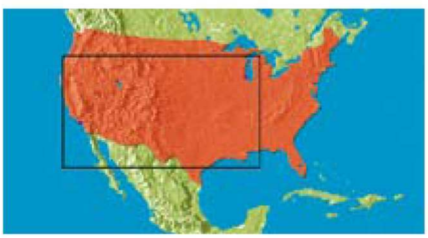
Give us a call. We'd like that.

We make the things that make communications work.™

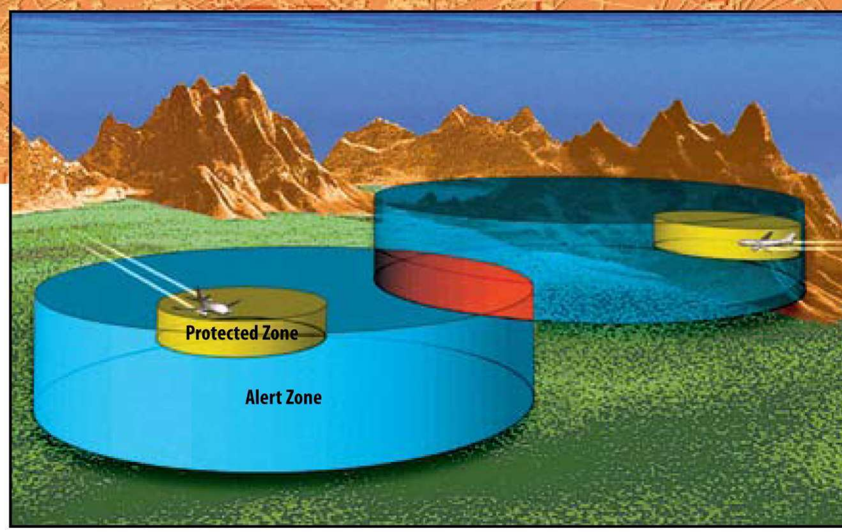
Shorter, Faster, Cheaper

Even if the itinerary says "direct," assigned routes can be adding kilometers—and dollars and minutes—to your flight. Free flight could end all that.





As the crow flies: With clear weather and no winds to avoid (or exploit), a plane could take the shortest route between two cities. In the example above, the trip would be 259 km shorter than an assigned FAA route.



BETSY HAYES; SOURCES: FAA/WILLIAM B. COTTON

They need their space: Electronic surveillance zones might someday protect planes. Any overlap of alert zones would prompt course changes, keeping protected zones inviolate.

"conflict probe," would automate systemwide much of what human controllers now do in fragmented, sequential fashion in their individual sectors. While pilots and air dispatchers made or changed flight plans at will, the software would compare the plans with radar data, alerting controllers to any possible collisions between flights within the next, say, 10 or 15 minutes. Controllers would track flights as they do now, but only intervene to resolve such conflicts.

The other element of Baiada's minimalist scheme is "time-based sequencing" at the arrival end. This software would automatically determine each plane's place in the landing queue—one of the many operations controllers now perform in their heads. Not only would this make the stream of traffic on the runway more steady, it would also give each flight a precise landing slot to aim for. This would enable pilots to pace themselves and stay at higher altitudes (where planes are more fuel-efficient) until the last minute, rather than descending and then having to wait to land.

One thing that particularly galled Baiada was that he believed the FAA already had these tools and wasn't taking advantage of them. In particular, Baiada wanted to see the agency implement a piece of conflict-probe software developed by FAA computer scientist Norman Watts and contractor Lonnie Bowlin. The software impressed some FAA researchers, managers and controllers, but after testing it at the Boston en-route center in 1995-96, the agency decided to go with a product from Mitre instead.

By then, Baiada had already left his post under Cotton (though he continues to fly for United). He started waging his free-flight crusade in op-eds for the aviation press, conferences and every other forum he could find. Today, Cotton dismisses him as "a stonethrower" who's burned too many bridges to be effective. Baiada insists that stonethrowing was the only way to get any action.

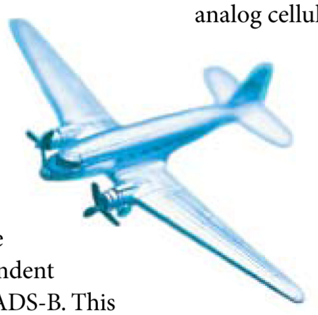
Free Flight Lite

WHILE BAIADA WAGED HIS LONELY CRUSADE, the FAA's Flight 2000 scheme crashed and burned, thanks to lack of industry (and, consequently, congressional) support. Now two projects, each on a much smaller and more conservative scale, are rising from the failed plan's ashes *(see "The Technologies Behind Free Flight," p. 52)*. Ironically, each one puts into practice the ideas of one of the two allies-turned-antagonists, Cotton and Baiada.

One of the two current efforts, known as Safe Flight 21, incorporates two trials of the avionics approach pioneered by Cotton. In a slice of the original all-Alaska test bed, small planes—which fly outside of

ground control—will use the Flight 2000 technologies in an attempt to improve safety. Safe Flight 21's other component tests the same avionics in an interesting new sector: air cargo companies.

Because cargo companies haven't had to install TCAS (as passenger carriers have), they are particularly interested in one technology under study in Safe Flight 21 that might provide an even better collision-avoidance solution: Automatic Dependent Surveillance Broadcast, or ADS-B. This system transmits position, identification, velocity and direction information from cockpit to cockpit and cockpit to ground. And it doesn't hurt that United Parcel Service (UPS) has backed the project as both a user and supplier of the new technology: Its subsidiary UPS Aviation Technologies makes the ADS-B units being tested.



ADS-B performed well in initial Safe Flight 21 tests this summer. And though ADS-B hasn't yet been proven as an avoidance system, UPS Airlines spokesman Ken Shapero is confident it will be: "Eventually, passenger airlines will want ADS-B for collision avoidance. It's like digital versus analog cellular phones."

By leapfrogging over TCAS (an analog system with relatively short range) to digital, wider-range ADS-B, with its richer store of data, the carriers hope to get collision avoidance and much more. How much more? Maybe free flight, someday; UPS is driving to make ADS-B free flight's base technology. "If we get the technology in place, then we can figure out applications," argues Shapero. "The FAA failed with some Big Bang programs for which no technology existed, *then* tried to make the technology work."

The other current free flight initiative, Free Flight Phase 1, is a streamlined approach that happens to follow the same principles Baiada urges—act now, without waiting for any more newfangled technologies to come online. This scheme was prompted partly by the failure of the grander free-flight scheme. In mid-1998, the FAA was desperate to chalk up a success and show its commitment to modernization under a new administrator, Jane Garvey. "The industry and the agency got together and realized they needed to bring out something quicker, sooner, better," says Free Flight Phase 1 assistant manager Robert Voss, echoing NASA's "faster, better, cheaper" mantra.

Free Flight Phase 1's incrementalist mission seems to have been drafted to defuse fears of over-reaching.

Thus was Free Flight Phase 1 born in July 1998, with a substantial budget but a mission that seemed drafted to defuse fears of over-reaching: "To introduce modernization into the national air system incrementally—taking a building block approach to fielding new systems to provide benefits to users as soon as possible." Forget the fancy avionics; Free Flight Phase 1 would deploy software capabilities already available or in development to streamline ground-based control.

Is Half a Cheer Better Than None?

FREE FLIGHT PHASE 1'S "FREE FLIGHT LITE" approach and the pared-back avionics trials of Safe Flight 21 get cheers from the airlines, which have long pitched for such closely focused, cost-conscious approaches, and the traffic controllers, who are relieved that neither program threatens to eliminate their jobs. But free flight's early advocates give perhaps only half a cheer. "They're starting to implement free flight," Cotton says, "but much too slowly." Baiada actually agrees with Cotton on this point: "Free Flight Phase 1 would have been a good program—20 years ago."

Mighty Atom

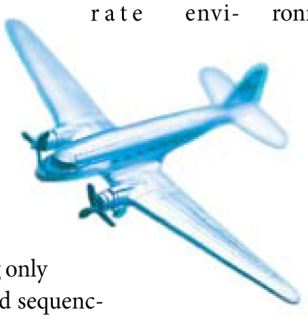
Lonnie Bowlin turned to aviation systems after designing remote-sensing, trajectory-analysis and orbital-location technology for NASA. He says his experience enabled him to pinpoint two flaws in the way air traffic is now managed: First, system designers use planar geography, "as though the world were flat." That works well enough for controllers moving planes through 300-kilometer-long sectors—but not for direct routes thousands of kilometers long. (Bowlin approaches the problem as an ellipsoidal orbit system.) What's more, he says, air traffic management is conceived "piecemeal": Throw in this technology, add this capability, and see where it all gets us.

Two years ago, Bowlin's Landover, Md.-based company, Aerospace Engineering, decided to go beyond this "one-up" approach. "We went to a blank sheet of paper," he recounts, and came up with what he calls "the first integrated air traffic management system," running everything from traffic routing to departure-lounge information screens with the same software and database. The resulting system, dubbed "atom," is the air traffic control system with something for everyone. It includes conflict probe, time-based sequencing and dynamic sectorization, a tool that would better distribute the workload among controllers, and one which the FAA is still only researching. Bowlin says it's capable of free flight but also of conventional control. It can work on Windows NT, using Pentium II processors—or on the FAA's current host computer.

Atom's maiden flight is being undertaken by another Bowlin client: Inter-Caribbean Aeronautical Communications, which manages air traffic control for Trinidad and several other Caribbean islands. Inter-Caribbean's operations manager, Ewart Boiselle, says the company was initially attracted by a more prosaic feature of Bowlin's integrated approach: Atom automatically fills and prints out "flight strips." These documents, which the Inter-Caribbean controllers fill out manually for each flight, are used to track flights and bill airlines for air space. "Before, controllers didn't have time to write them all down," says Boiselle—and if they didn't, the airlines would get off free. "Now the controllers have more time to do air traffic control. It saves us a lot of trouble."

So far, says Boiselle, atom's been "very successful" in Trinidad. "Eventually, it will work for free flight," says Inter-Caribbean general manager Andre McIntyre. For the moment, no one at FAA headquarters seems to be paying much attention.

Indeed, the three-year Free Flight Phase 1 program is neither breaking new technological ground nor implementing systemwide improvements. "It's just another R&D effort," laments Michael Goldfarb, a former FAA chief of staff who's now in private consultancy. "They're spending hundreds of millions on disparate things, none of which talk to each other," Goldfarb says. "The FAA hasn't figured out the concept of *operations*."



For his part, Baiada remains adamant that a stripped-down scheme, using only conflict probe and time-based sequencing, could achieve 70 percent to 90 percent of free flight's eventual efficiency in just "three to five years." All it would take, Baiada says, is a $500 million investment in off-the-shelf software to be installed in the current infrastructure. And again, the software he believes to be capable of getting the job done comes from Lonnie Bowlin's company, Aerospace Engineering *(see "Mighty Atom," p. 51)*.

Although Baiada believes in this system, he harbors few illusions that the FAA and airlines will hurry to implement this or any other broad free flight scheme anytime soon. There is simply too much inertia in the system for major changes now. Indeed, many consider it a victory that the FAA has even begun to update some very old-fashioned equipment.

Early this year, for example, the agency began replacing controllers' display screens, finally switching to the sort of windows-type, mouse-controlled graphical interface that's taken for granted in almost every other work environment. The new display system might also ease implementation of other new software.

But incremental changes like this one have little to do with the massive task that surely lies ahead somewhere: rebuilding the entire system. This is a challenge that gives pause even to advocates of radical change.

"The system is so old and the technologies so huge," says Lonnie Bowlin, "no one understands it in toto." And yet it must operate 24 hours a day, preventing disaster in the skies; changing anything in such a system, FAA, airline, and controllers' union officials have all been heard to say, "is like changing a tire at 70 miles an hour."

Still, the fact remains that if you want to keep driving, you have to find a way to change the tires. Baiada, never at a loss for a plan, has an answer. The FAA, he says "should build a second parallel system from scratch. We should have two air traffic control systems running at all times—one operational, the other next-generation, being developed."

That notion might unnerve congressional budget-writers, FAA officials and airline executives, whose ears are still ringing from past failed attempts at large-scale overhaul of the air traffic control system. But in the not-so-distant past, congressional and media critics were agitating for the elimination of the FAA and privatization of air traffic control—a move some other nations have made already. If the current incremental approach fails, predicts Karl Grundmann, the National Association of Air Traffic Controllers' free-flight liaison, "all the calls to do away with the agency will rise again." With gridlock looming, the agency's survival, not to mention passengers' mobility and the airlines' bottom line, may well depend on making free flight work. ◊

"The FAA hasn't figured out the concept of operations," says a former chief of staff. But the agency's future may depend on it.

The Technologies Behind Free Flight

TECHNOLOGY	FUNCTION	SOURCE
Included in Safe Flight 21:		
Automatic-Dependent Surveillance Broadcast (ADS-B)	Improved separation, "see and avoid," taxiway navigation, surveillance in nonradar air space, perhaps collision avoidance	UPS Aviation Technologies, Lockheed-Martin, Sensis, SETA, Harris
Datalink transceiver	Digitized radio communications	Honeywell, UPS Aviation Technologies, or Aviation Data Systems Innovations
Traffic Information Services-Broadcast (TIS-B)	Broadcasting traffic, weather, and other data from the ground to the cockpit	Undetermined; planned for year 2000
Cockpit Display of Traffic Information (CDTI)	Displays ADS-B and TIS-B data, controllers' instructions	ADC
Global Positioning System (GPS)	Navigation, location	UPS Aviation Technologies (receivers)
Digital terrain database with moving map	Crash avoidance	AlliedSignal, for UPS Aviation Technologies
Included in Free Flight Phase 1:		
Center-TRACON Automation System (CTAS)	Suite of automation tools for airport-approach and en-route control centers	NASA Ames Research Center
User-Request Evaluation Tool (URET)	Conflict probe	Mitre
Collaborative Decision Making (CDM)	Real-time exchange of scheduling data and changes by airlines and air space managers	More than 50 airlines, federal agencies, universities, research and industry organizations participating
Controller-Pilot Data Link Communications (CPDLC)	Limited ground-air digital communications	FAA
Surface Movement Advisor (SMA)	Provides airlines with aircraft arrival information for better runway routing	FAA


government
suppliers
e-procurement
financial

Mining the Genome

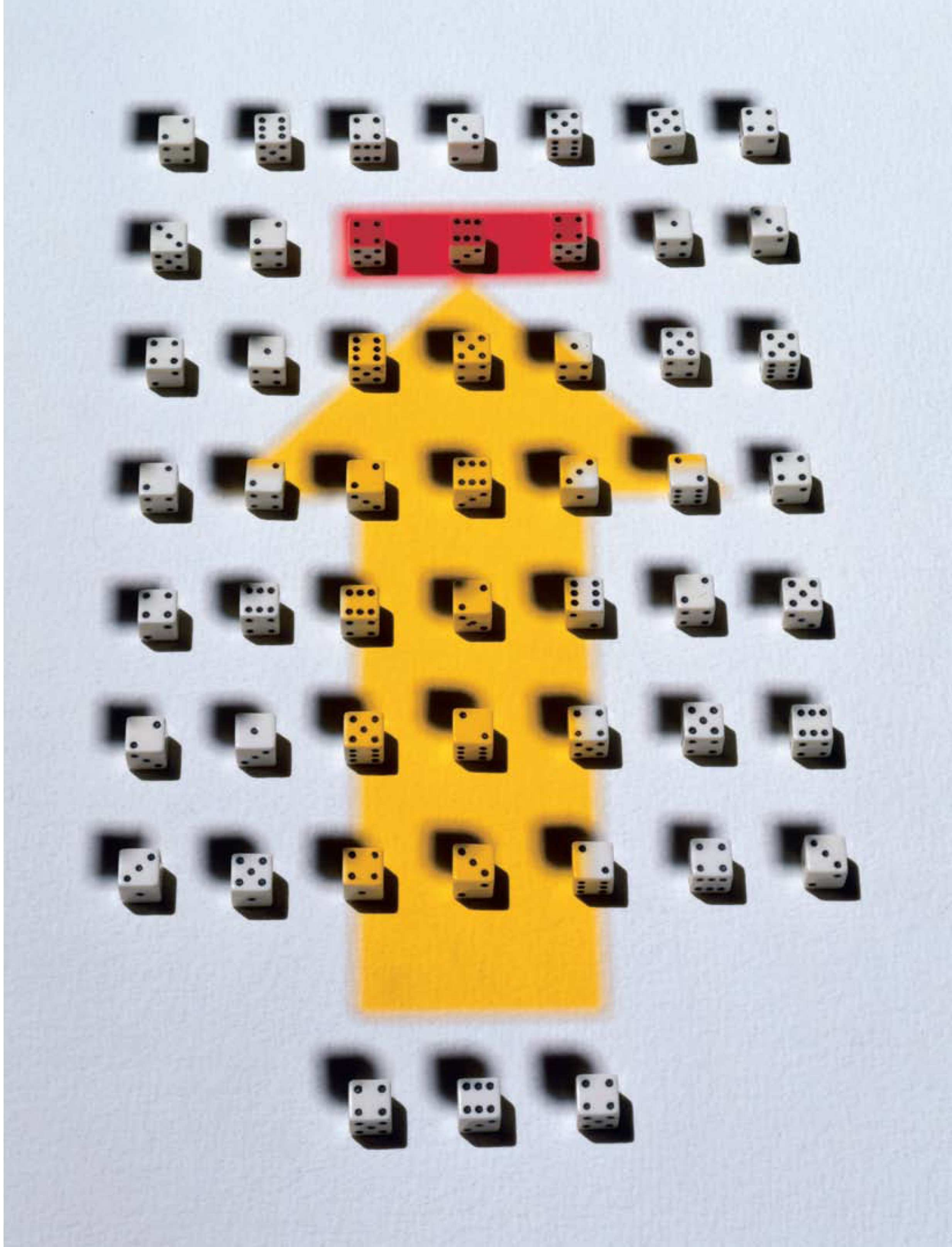
The Human Genome Project has piled up a mountain of data. How will companies extract the gold of new drugs? One emerging tool may hold the key: pattern- finding software that uncovers the richest veins.

BY ANTONIO REGALADO

LARRY HUNTER HAD JUST MOVED INTO HIS new office when a reporter visited, so the room lacked knickknacks and family snapshots. Hunter had, however, started unpacking his books, and they were already beginning to form an interesting pattern. Roger Schank's *Dynamic Memory*, a classic title in artificial intelligence, was shelved next to Georg Schulz's *Principles of Protein Structure*. *Machine Learning* flanked *Oncogenes*. *Artificial Life* leaned on *Medical Informatics*.

Properly interpreted, the pattern on Hunter's bookshelf reveals the latest trend in biology, a field now so overwhelmed by information that it is increasingly dependent on computer scientists like Hunter to make sense of its findings. An expert in an offshoot of artificial intelligence research known as machine learning, in which computers are taught to recognize subtle patterns, Hunter was recently lured from a

PHOTO-ILLUSTRATION BY PIERRE-YVES GOAVEC



solitary theoretical post in the National Library of Medicine to head the molecular statistics and bioinformatics section at the National Cancer Institute (NCI)—a group formed in 1997 to use mathematical know-how to sift the slurry of biological findings.

Where is all the data coming from? The simple answer is that it's washing out of the Human Genome Project. Driven by surprise competition from the commercial sector, the publicly funded effort to catalog

Pattern-master: Larry Hunter, an expert in machine learning, applies math to biology at the National Cancer Institute.

the estimated 100,000 human genes is nearing its endgame; several large academic centers aim to finish a rough draft by next spring. By then, they will have dumped tens of billions of bits of data into the online gene sequence repository known as GenBank, maintained by the National Center for Biotechnology Information (NCBI) at the National Institutes of Health (NIH) in Bethesda, Md. And DNA sequences aren't the only type of data on the rise. Using "DNA chips," scientists can now detect patterns as thousands of genes are being turned on and off in a living cell—adding to the flood of findings.

"New kinds of data are becoming available at a mind-blowing pace," exults Nat Goodman, director of life sciences informatics at Compaq Computer. Compaq is one of many companies seeking an important commercial opportunity in "bioinformatics." This congress of computers and biology is a booming business, but has so far revolved mostly around software for generating and managing the mountain of gene data. Now, pharmaceutical companies need ever-faster ways to mine that mountain for the discoveries that will lead to new treatments for disease.

That's where entrepreneurial researchers such as Larry Hunter come in. On Hunter's bookshelf sits a glass bauble reading: "$2,000,000 Series A Preferred. March 5, 1999"—a celebration of venture capital funds raised by Molecular Mining, a company he co-founded. The firm, based in Kingston, Ontario, hopes to use data-mining methods to help pharmaceutical companies speed the development of new drugs by identifying key biological patterns in living cells—such as which genes are turned on in particularly dangerous tumors and which drugs those tumors will respond to. And a dozen other startups—the biotech industry's best indicator of a hot trend—have been formed to make data-mining tools *(see "The Genome Miners," p. 59)*. "Biology," Hunter predicts, "will increasingly be underpinned by algorithms that can find hidden structure in massive amounts of molecular data." This kind of data-mining work, which Hunter specializes in, is often known as "pattern recognition" and it's one of the fastest-moving areas in bioinformatics. Indeed, if Hunter is right, pattern recognition might turn out to be the pick that brings forth the gold of new therapies.

First You Have to Find Them

TO GET A SENSE OF HOW BIG THE MOUNTAIN Hunter and his colleagues are tunneling into, consider the fact that every human cell has 23 pairs of chromosomes containing about 3.5 billion pairs of nucleotides, the chemical "letters" A, C, G and T that make up DNA's genetic code. But the actual genes that carry code to make proteins, and go wrong in genetic diseases and cancer, occupy less than 3 percent of the genome; the rest is genetic noise. Making genes still trickier to unearth is the fact that their protein-coding elements are scattered, as are the genetic signals that the cell uses to stitch them back together and guide their "expression": the process that activates them to make proteins. "The key to understanding the genome is understanding the language of these signals," says David Haussler, a leading computational biologist at the University of California at Santa Cruz. "But they are hidden, and they are noisy."

The first crucial problem is to extract them from this maze of irrelevant code. At Oak Ridge National Laboratory, Edward Uberbacher's Computational Biosciences Section has tackled the gene-finding problem with artificial neural networks—a type of artificial intelligence (AI) program distinguished by its capacity to learn from experience. At Oak Ridge, neural nets had been used for jobs such as recognizing enemy tanks in fuzzy satellite images; in 1991, Uberbacher adapted these methods to create a program, called GRAIL, that can pick out genes. Since then, GRAIL has been joined by at least a dozen other gene-finding programs, many of which are available to researchers online.

The current gene-locating programs are far from perfect, sometimes predicting genes that aren't real and often missing genes that are. Partly because of accuracy problems, says Uberbacher, "these methods have been on the fringe for a while." But given the accelerating flood of genome data, biologists will be forced to rely on—and improve—them. "Imperfect as they are, they are the best place to start," says Lisa Brooks, program director of the National Human Genome Research Institute's genome informatics branch, whose operation doles out $20 million a year to support bioinformatics databases and to develop new data-mining methods.

Pattern-recognition programs aren't used only for discovering genes; they're also heavily exploited to give researchers clues as to what genes do. Today the most widely used program—the NCBI's Basic Local Alignment Search Tool, or BLAST—receives 50,000 hits per day from researchers searching for similarities between newly discovered DNA sequences and ones whose roles are already understood. Given similar sequences, scientists can often deduce that two genes have similar functions.

In researchspeak, the process of interpreting a gene's function and entering it into a database is called "annotation." In May, London's Sanger Center and the Euro-

PHOTOGRAPH BY CHRIS HARTLOVE

pean Bioinformatics Institute (EBI), a branch of the multinational European Molecular Biology Laboratory in Hinxton, England, announced a hastily organized project known as EnsEMBL. The goal of EnsEMBL, says EBI's Alan Robinson, is "to make sure the first draft of the human genome will have annotation attached." EnsEMBL's first activity will be to send out gene-finding algorithms to rove the genome and bring back a rough picture of where the genes are—a prospector's hand-drawn map. With the map drawn, EnsEMBL will use tools such as BLAST to guess at the genes' functions.

Plans for computerized discovery pipelines like this one are important to pharmaceutical companies, who are racing to identify—and patent—key disease-causing genes. In June, for example, the German drug giant Bayer agreed to pay a Heidelberg startup, Lion Bioscience, as much as $100 million for an automated system to mine genetic databases. Lion has dubbed the computerized approach "*i*-biology," according to its head of bioinformatics Reinhard Schneider, and is promising Bayer that in five years its computers will discover 500 new genes, as well as annotate 70 genes Bayer has already found. Pattern-recognition algorithms, which will drive the daily scourings of the databases, lie at the core of *i*-biology.

Although the Bayer-Lion pact is a record-breaker, it is just one among dozens of data-mining alliances between pharmaceutical giants and computationally savvy startups—evidence that mathematical methods are taking center stage in genomic research. And the academics who write the algorithms also find their stars rising, especially in industry. Lion was founded by top bio-infonauts from the European Molecular Biology Laboratory, headquartered in Heidelberg. At Celera Genomics, the Rockville, Md., company whose plans to decipher the genetic code have shaken up the Human Genome Project and accelerated the publicly funded work, success rides on the expertise of pattern analysis expert Eugene Myers. Celera lured Myers from a tenured position at the University of Arizona to head its informatics efforts, hiring Compaq to build him what's being touted as the world's most powerful civilian supercomputer *(see "The Gene Factory,"* TR *March/April 1999)*. According to Haussler, most scientists think the success of Myers' methods will "make or break" Celera.

> Computer-aided pattern recognition will help pharmaceutical companies identify—and patent—key disease-causing genes: Bayer is paying $100 million for an automated system to mine genetic databases.

Cancer Categorizer

CRUCIAL AS THEY ARE, IDENTIFYING AND comparing genes for clues to their function are just first steps on a long path toward medical relevance—developing a drug can take many years longer. But computational scientists say pattern mining could have much nearer-term payoffs when applied to another type of genomic data known as "gene expression profiles."

A gene's expression level refers to how many copies of its specific protein it is being called upon to make at any given time. The proteins are the actual workhorses in the cell, carrying out the daily tasks of metabolism; the levels of each can vary dramatically over time, and are often out of kilter in diseased cells. Thanks to devices known as DNA microarrays, or, more familiarly, "DNA chips," scientists can now for the first time regularly measure the expression levels of thousands of genes at once. DNA chips take advantage of the fact that to make a protein, a cell first

The Genome Miners

A sampling of companies specializing in pattern-recognition software

COMPANY	LOCATION/WEB SITE	HIGHLIGHT
Bioreason (private)	Santa Fe, N.M. www.bioreason.com	Artificial intelligence software makes sense of chemistry data.
Compugen (private)	Tel Aviv, Israel www.compugen.co.il	Ex-Israeli defense contractors are scoring big in genetic data-mining. Customers include U.S. Patent Office.
IBM (public)	Armonk, N.Y. www.research.ibm.com	Advanced pattern-recognition algorithms power a 1997 Monsanto alliance for protein discovery.
Lion Bioscience (private)	Heidelberg, Germany www.lionbioscience.com	$100 million pact with drug giant Bayer sets a bioinformatics record.
Molecular Mining (private)	Kingston, Ontario www.molecularmining.com	Raised $2 million in startup funds from venture capitalists in March.
Neomorphic (private)	Berkeley, Calif. www.neomorphic.com	Hidden Markov models are among this 1996 startup's advanced gene-finding tools.
Partek (private)	St. Peters, Mo. www.partek.com	Neural networks specialists moved into biology market in 1998.
Silicon Genetics (private)	San Carlos, Calif. www.sigenetics.com	Stanford spinoff mines gene data for profit.
Silicon Graphics (public)	Mountain View, Calif. www.sgi.com	Mine Set visual data-mining tool is popular in the financial, telecom and drug industries.

{The honest-to-goodness truth

If we had just removed the roof,

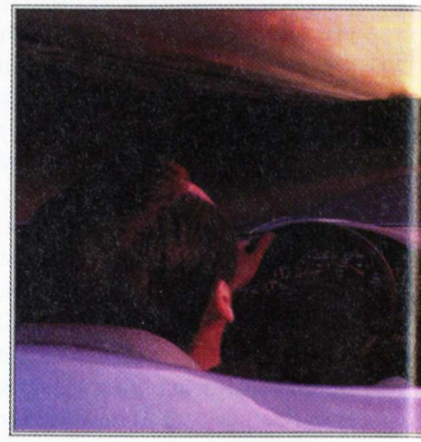
By David Hill, Corv

One of the primary objectives when we designed the C5 Corvette® was to make sure it handles superbly. We would not be happy with

{ The coupe has the same stiff structure, rear-mounted transaxle and revised suspension as the convertible. }

anything short of an outstanding sports car, whether a coupe, convertible or hardtop. It was critical that we didn't just take the coupe and chop off the top to make a convertible. The fact is, the C5 Corvette was designed as a convertible right from the outset. It was the best way, the only way in our minds, to make a car with extraordinary feel and handling.

Stiffness and Strength We didn't want this car to suffer from the ride setbacks other convertibles typically have. One particular concern was how to avoid cowl shake, a common side effect of removing a car's roof. So, we made the structure very rigid. The previous 48-piece frame rails were replaced with twin seamless hydroformed tubes. Our new hydroformed frame rail is much more durable than a welded-up one. In fact, the structure was tested to endure up to three life-times of Corvette usage. And not only is the C5



{ The C5 was designed without a roof from the start so we

four times stiffer structurally than its predecessor it also has a lower curb weight. The difference in rigidity is immediately noticeable; lateral shake is virtually gone, even in the absence of a structural crossover bar.

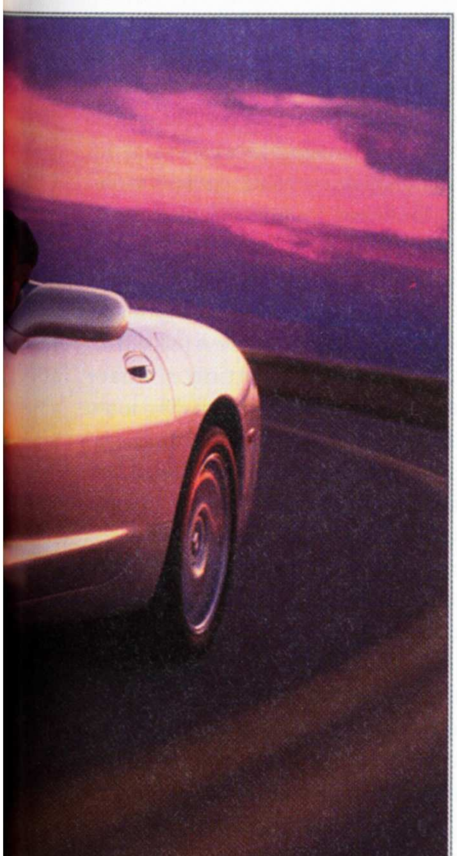
about the C5 Corvette, after all.}

it would have been a tragedy.

ette Chief Engineer

could make a world-class sports car that's also a convertible. }

A User-Friendly Convertible Once we perfected the structure, our next priority was to make every millimeter of the car work for the driver, especially in terms of comfort, spaciousness and cargo. We wanted the car to be easy on the driver, a rare feat in convertibles. So, the controls and functions were placed where it would be natural to reach for them. Entry and exit are easier because door-sills are almost four inches lower. We've increased the hip, shoulder and leg room. There is four times more cargo space with the top down than with a C4. Partly responsible for this are the run-flat tires, which make a bulky and weight-adding spare tire unnecessary. (The instrument panel will alert drivers when a tire needs air.) These measures were taken simply because we wanted customers to avoid inconvenience wherever possible.



Power and Performance An obvious worry was whether we would lose the true spirit of a sports car by making it too civilized. We went to great lengths to keep that spirit alive. The 1999 Corvette has an aluminum small-block V8 that produces 345 horsepower at 5600 rpm, 350 lb.-ft. of torque at 4400 rpm and, in coupe form, achieves a top speed of around 170 mph.

Although it delivers more horsepower and torque than the iron version it succeeds, the C5 engine weighs 44 pounds less and is smaller in size. Basically, we packed more power into a more compact unit. We could keep the hoodline low, which would improve both aerodynamics and driver visibility.

Making No Compromises Perhaps the most vocal customer opinion was that they wanted a no-compromise sports car; they didn't want to sacrifice ride comfort for the sake of performance. We found breakthrough methods to meet those requirements. Like the composite, balsa wood-cored floor. It minimizes vibrations for the cockpit occupants, while being both lightweight and strong enough to help deliver a more fatigue-free driving experience.

The stiff structure and revised suspension

{ Design attributes like the nostalgic waterfall make the C5 immediately recognizable as a Corvette. }

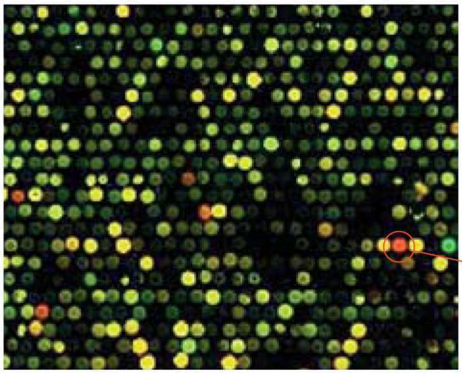
also demonstrate how there are no take-aways in the C5 convertible. By shifting the transaxle to the rear, we opened up more leg room. This also freed up room for a structural tunnel down the middle of the car, which increased its rigidity. That rigidity lets the suspension do its job properly; instead of compensating for chassis flex, it can focus on the most important things: precise handling and a smooth ride.

A True Corvette The C5 convertible proves it is possible to marry high performance with top-down freedom. Simply put, this thing is incredible. It will far exceed people's expectations. It even exceeded mine. See why on the showroom floor.

Hunting for Patterns in the Code of Life

Gene patterns caused by a drug help scientists understand how it works and why it causes side effects.

A



EXPERIMENT

Detail of a DNA microarray, a glass slide covered with probes that simultaneously measure the activity levels of all 6,200 genes of baker's yeast (S. cerevisiae). After treatment with the immune-suppressing drug FK506 (tacrolimus), some genes become more active (green) while the level of others is repressed (red).

B

GENE I.D.	GENE NAME(S)	CHANGE
YBR005W	unknown	-8.5
YMR316W	unknown	-6.3
YMR316C-A	unknown	-4.8
YOL016C	CMK2	-4.7
YBR296C	PHO89	-3.7
YOR385W	unknown	-3.2
YEL060C	PRB1,CVT1	-3.1
YOR220W	unknown	-2.8
YLR120C	YAP3,YPS1	-2.7
YGR032W	GSC2,FKS2,GLS2	-2.5
YLR194C	unknown	-2.4
YFL032W	unknown	-2.3
YFL031W	HAC1,ERN4,IRE15	-2.2
YPL057C	SUR1,BCL21,LP...	-2.0

DATA

In tabular format, the data are hard to interpret. Genes whose roles are understood have been given names, but the functions of many are still unknown.

"translates" a gene into multiple copies of a molecule called messenger RNA (mRNA). The type and quantity of mRNAs in a cell correspond to the proteins on order—and by measuring the levels of thousands of different mRNAs at once, DNA chips are able to create a snapshot of the activity of thousands of genes.

Mark Buguski, senior investigator at NCBI, says the new data on gene expression levels are "unlike anything biologists have ever been exposed to." Before, biologists could only analyze the activity of a few genes at a time. Now, DNA chips can produce a "massively parallel" readout of cellular activity. That's an important advance, because the difference between health and disease usually lies not in the activity of a single gene but in the overall pattern of gene expression.

A team at the Whitehead/MIT Center for Genome Research is putting this massively parallel readout to work identifying telltale differences between different cancers. Known as the Molecular Pattern Recognition group, it was started last year by genome center director Eric Lander and is led by molecular biologist Todd Golub. Other members include ex-IBM mathematician Jill Mesirov, computer scientist Donna Slonim, and computational physicist Pablo Tamayo, who joined Whitehead from the supercomputer company Thinking Machines.

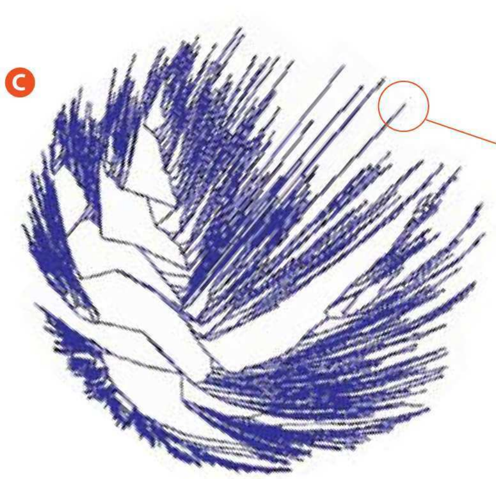
This interdisciplinary brain trust is trying to solve an enormously important problem in pattern recognition. Tumors vary in subtle ways, and cancer cells that look the same under a microscope respond very differently to drugs. "The things we call a single type of cancer are surely many types of cancer," says Lander, "but we don't know what [differences] to look for."

To provide a benchmark for the new methods, Lander's group started with two types of leukemia that can already be distinguished under the microscope: acute myeloid leukemia (AML) and acute lymphoid leukemia (ALL). They measured the levels of about 6,800 different genes in bone marrow samples from 38 leukemia patients, which they would mine for patterns that could distinguish AML from ALL. But working with 6,800 parameters (the genes) and only 38 data points (the samples) made for a task akin to trying to forecast an election by polling a dozen people. After running through a year's supply of pencils and scratch paper, they hit on a solution.

A key step involved feeding the data points into a learning algorithm known as a "self-organizing map." By plotting the 38 samples into a high-dimensional mathematical space, the map algorithm was able to partition the samples into two groups—one for each type of cancer. Checking against information about the known tumor types, Lander says, it became clear that the clusters broke out the ALL and AML samples almost perfectly. "We showed that if you hadn't known the distinction between these two types of leukemias—which in fact took 40 years of work to establish—you would have been able to recapitulate that in one afternoon," he says.

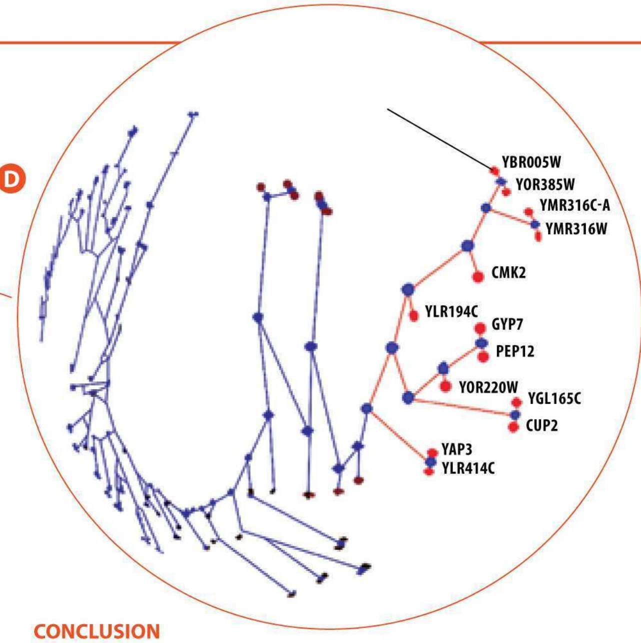
The research team also got an inkling of how valuable their methods (still unpublished as *TR* went to press) could be for patients. At one point, the algorithms failed to categorize a sample into either of the leukemia categories. Was the math flawed? No—the diagnosis was. Prompted by the program's result, doctors took another look and found what they had believed was leukemia was in fact a highly malignant muscle cancer, for which the patient is now being treated. At Cambridge, Mass.-based Millennium Pharmaceuticals, researchers are betting similar approaches will lead to "optimal diagnostic tests" for cancer, according to Dave Ficenec, a former astrophysicist hired by Millennium to install the latest data-mining algorithms in its in-house software. The company collaborates closely with Lander's center—Lander is a Millennium co-founder who sits on the company's board of directors.

The new parallel methods for making snapshots of gene expression are also being used to evaluate new drug candidates. At startup Rosetta Inpharmatics in Kirkland, Wash., a scientific team is assembling and mining databases for gene patterns to



CLUSTERING

Mathematical "clustering" produces a tree that groups genes according to how similar their behavior patterns are. In this case the data come from 1,000 different experiments.



CONCLUSION

A tree branch shows that genes repressed by FK506 (in B) are closely related members of a single biochemical process. FK506-affected genes not in this cluster could cause side effects.

BETSY HAYES

speed drug discovery. Rosetta studies yeast cells, exposing them to potential new drugs and then analyzing levels of gene expression for clues to the drugs' actions. For example, the cells can be rapidly checked to see whether their response matches a pattern typical of toxic side effects. Tossing out such losers early on is part of Rosetta's program of "improving the efficiency of drug discovery," says Stephen Friend, who doubles as Rosetta's chief science officer and head of the molecular pharmacology program at Seattle's Fred Hutchinson Cancer Research Center. Drug firms have taken notice, with eight signed up as Rosetta partners.

With the explosive growth of bioinformatics drawing many of the best university teachers and researchers into the private sector, many wonder who will train the next generation of computational biologists.

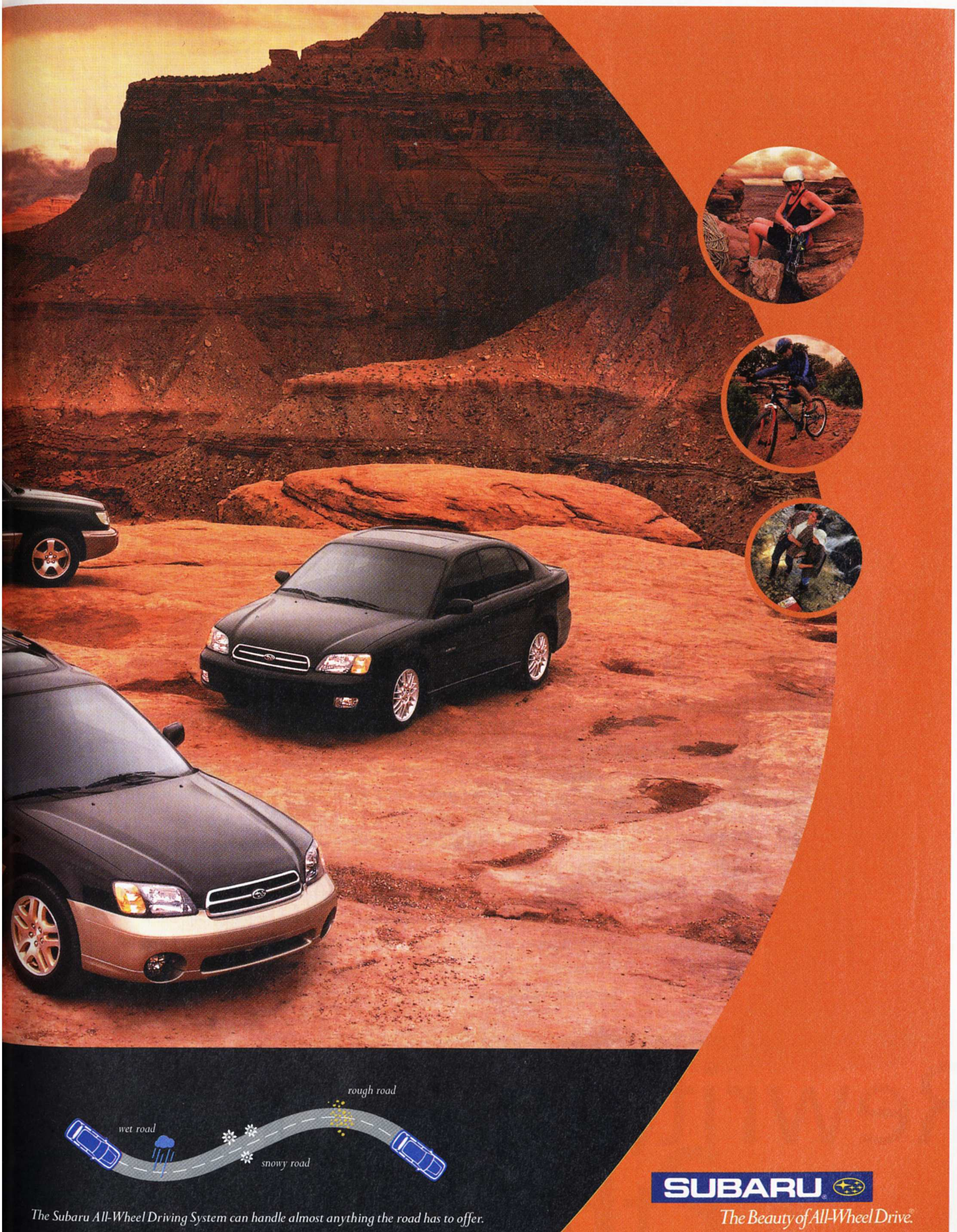
Brain Drain

WHILE RESEARCHERS AT COMPANIES AND universities are jumping on the data-mining bandwagon, they are likely to encounter plenty of bumps in the road ahead. Some investors, for instance, remain concerned that databases of different biological results are still poorly interconnected, and sometimes of uneven quality. Says Larry Bock, an investor at the Palo Alto office of the venture firm CW Group: "It may be a bit early for data-mining, since your ability to mine is directly related to the quality of the database." Still, says Barbara Dalton, vice president at the venture firm SR One in West Conshohocken, Pa., "the long-term prospects look good." SR One, along with Princeton, N.J.'s Cardinal Health Partners, anted up $2 million to finance Larry Hunter's startup, Molecular Mining. "Data-mining is going to be a core part" of drug discovery, Dalton predicts.

But before that happens, the field may have to break its most serious bottleneck: an acute shortage of mentors. Bioinformatics has grown explosively during the 1990s, drawing many of the best university teachers and researchers into the high-paying private sector. "We went from very little interest in bioinformatics, to—Bang!—having most of the people working in companies," says Mark Adams, who left the academic track to work for the Cambridge, Mass., biotech company Variagenics. With universities drained of some of their brightest minds, many wonder who will train the next generation of computational biologists.

Part of the answer came in June, when a special advisory panel convened by NIH director Harold Varmus concluded the U.S. government should spend as much as $10 million to fund 20 new "programs of excellence" in biomedical computing. Several universities have also gotten into the act, including Johns Hopkins, where a new computational biology program is under way, thanks to a $2.5 million grant from the Burroughs Wellcome Fund. Stanford, Princeton and the University of Chicago are all planning major centers that will bring physical scientists together with biologists.

In industry, the convergence is already reality. One-third of Rosetta Inpharmatics' 100 employees are computational scientists, drawn from fields as diverse as sonar detection, air traffic control and astrophysics. Chief scientist Stephen Friend says he's come to an important realization since joining the company in 1997. Biologists may still ask the best questions and design the most compelling experiments, he says, but "the best answers are coming from the physicists or mathematicians." Those answers are likely to lead to important new therapies—gold extracted from the mountains of the Human Genome Project by the tools of pattern recognition. ◊


rough road
wet road
snowy road
The Subaru All-Wheel Driving System can handle almost anything the road has to offer.
SUBARU
The Beauty of All-Wheel Drive.

Rewriting the Bible in 0's and 1's

BY STEVE DITLEA

PHOTOGRAPHS BY ANNE HAMERSKY

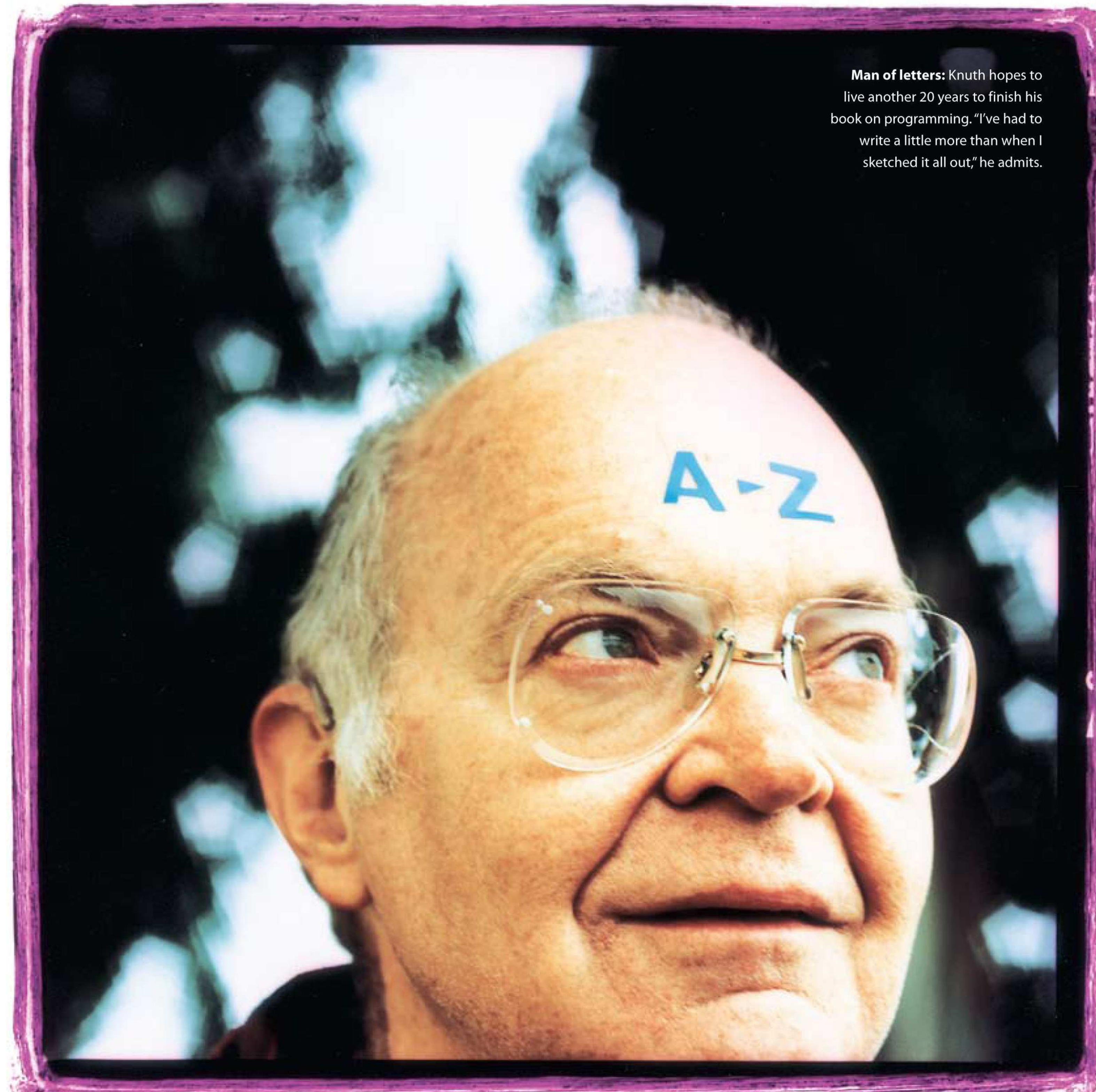
> Since the 1960s, Donald Knuth has been writing the sacred text of computer programming. He's a little behind schedule, but he has an excuse: He took time out to reinvent digital typography.

When you write about Donald Knuth, it's natural to sound scriptural. For nearly 40 years, the now-retired Stanford University professor has been writing the gospel of computer science, an epic called *The Art of Computer Programming*. The first three volumes already constitute the Good Book for advanced software devotees, selling a million copies around the world in a dozen languages. His approach to code permeates the software culture.

And lo, interrupting his calling for nine years, Donald Knuth wandered the wilderness of computer typography, creating a program that has become the Word in digital typesetting for scientific publishing. He called his software TeX, and offered it to all believers, rejecting the attempt by one tribe (Xerox) to assert ownership over its mathematical formulas. "Mathematics belongs to God," he declared. But Knuth's God is not above tricks on the faithful. In his TeX guide, *The TeXbook*, he writes that it "doesn't always tell the truth" because the "technique of deliberate lying will actually make it easier for you to learn the ideas."

Now intent on completing his scriptures, the 61-year-old Knuth (ka-NOOTH) leads what he calls a hermit-like existence (with his wife) in the hills surrounding the university, having taken early retirement from teaching. He has unplugged his personal e-mail account, posting a Web page (www.cs-faculty.stanford.edu/~knuth/) to keep the software multitudes at bay by answering frequently asked questions such as, "When is Volume 4 coming out?"

About once a month during the academic year, Knuth comes down from the heights to a basement lecture room in the Gates Computer Science Building at Stanford to deliver one of his "Computer Musings" lectures, usually about some aspect of his current work on *The Art of Computer Programming*. These talks draw computer science students, visiting professors, software engineers from nearby companies and an occasional CEO. On a balmy day earlier this



Man of letters: Knuth hopes to live another 20 years to finish his book on programming. "I've had to write a little more than when I sketched it all out," he admits.

year, the topic and listeners are different. To celebrate the publication of the third volume of his collected papers, *Digital Typography*, the associates of the Stanford University Libraries have invited an audience of fans of the printed word to hear Knuth talk about creating the TeX system for scientific and mathematical publication. Wearing a black T-shirt over a long-sleeve black shirt, his bald pate glistening in the overhead lights, he appears suitably monkish before about 70 acolytes and colleagues.

Hesitatingly, his words fighting his innate Lutheran modesty, he begins: "My main life's work and the reason that I started this whole project is to write a series of books called *The Art of Computer Programming*—for which I hope to live another 20 years and finish the project I began in 1962. Unfortunately, computer programming has grown over the years and so I've had to write a little more than I thought when I sketched it out." The faithful laugh knowingly.

> had to think of an endgame. How could I responsibly finish TeX and return to *The Art of Computer Programming*?"

Knuth relates his detour into digital typography during the 1970s. This was a time of enormous change in the typesetting industry, as computer systems replaced the hot type that had been used since the day of Gutenberg. Computer typography was less expensive, but also less esthetically pleasing—especially for complex mathematical notation. Recalls Knuth: "As printing technology changed, the more important commercial activities were treated first and mathematicians came last. So our books and journals started to look very bad. I couldn't stand to write books that weren't going to look good."

Knuth took it upon himself to write every line of code for software that yielded beautiful typography. He drew the name of his typesetting program from the Greek word for art—the letters are tau epsilon chi (it rhymes with "blecch"). Says Knuth: "Well over 90 percent of all books on mathematics and physics" are typeset with TeX and with its companion software, Metafont, a tool Knuth developed to design pleasing type fonts.

He is quick to acknowledge the contribution of the type designers, punch cutters, typographers, book historians and scholars he gathered at Stanford while developing TeX. Some are in the audience. He tells them: "TeX is what we now call open-system software—anybody around the world can use it free of charge. Because of this, we had thousands of people around the world to help us find all the mistakes. I think it's probably the most reliable computer program of its size ever."

Anyone who doubts this claim by the decidedly unboastful Knuth can find confirmation from Guy Steele, one of TeX's first users and now a distinguished engineer at Sun Microsystems. TeX, says Steele, was one of the first large programs whose source code was published openly. Steele says Knuth's publication of the TeX code in a book, along with full comments, made it so that "anyone could understand how it works and offer bug fixes." With academe's top scientists and mathematicians as beta-testers, an extraordinary quality control team helped perfect TeX. (The TeX development effort was a model for today's open-source software movement, which has given the world Linux—an operating system that is beginning to compete with Microsoft Windows.)

Perfectability is a major preoccupation of Knuth's. The only e-mail address Knuth maintains gathers reports of errata from readers of his books, offering $2.56 for each previously unreported error. (The amount is an inside joke: 256 equals 2 to the 8th power—the number of values a byte can represent.) Knuth's reward checks are among computerdom's most prized trophies; few are actually cashed.

He takes this error business very seriously. Engraved in the entryway to his home are the words of Danish poet Piet Hein:

The road to wisdom?
Well it's plain
and simple to express:

Err
and err
and err again
but less
and less
and less.

In a variation on this theme of perfectability, Knuth's contribution to computer science theory in the pages of *The Art of Computer Programming* has been his rigorous analysis of algorithms. Using methods in his book, the operations used to translate machine instructions into equations can be tested to determine whether they are optimal. Improving a program then becomes a question of finding algorithms with the most desirable attributes. Not that theoretical proofs can replace actually running software on a computer. In an often-cited remark he mentions on his Web page, he once warned a colleague: "Beware of the above code; I have only proved it correct, not tried it."

Bad Breaks

IN KNUTH'S STANFORD TALK, PERFECTABILITY WAS AGAIN A theme. He followed the pages in his volume on *Digital Typography* beyond its introductory chapters to the longest section in the book, which attacks a crucial problem in typography. He calls his listeners' attention to "one of the main technical tricks in the TeX system: the question of how to break up paragraphs so that the lines are approximately equal and good."

Poor spacing between words and ugly choices for line breaks had been among the major computer typography gaffes that launched Knuth on his TeX crusade. Odd word chasms, ladders of hyphens, and orphaned bits of text resulted from the rigid algorithms used to program line breaks without regard for visual elegance. Knuth's solution: have the computer use trial-and-error methods to test how each paragraph of text can best be broken up. Instead of "greedy" algorithms packing in the most words on a line—standard in computer typography before and after TeX—Knuth's computation-intensive method evaluates beauty.

Knuth seems born to the task of promoting beauty on the printed page—via computational methods. "I had a love of books from the beginning," he tells his audience. "In my mother's collection,

we found the first alphabet book I had. I had taken the letters and counted all the serifs." He is proud of his early literacy, telling a writer that he was the youngest member of the Book Worm Club at the Milwaukee Public Library. His interest in typographic reproduction also came early in life. One of his earliest memories of predesktop publishing was helping his father, Ervin, with the mimeograph stencils for printing the church newsletter in the basement. Like his father's newsletter, TeX was meant to be a homebrew project, on a manageable scale. "The original intent was that it would be for me and my secretary," he tells *TR* in an interview in his home's second-floor study. Leaning back in the black lounge chair, Knuth acknowledges that the long journey into TeX was intended to be a quick side trip: "I was going to finish it in a year."

Events took a different turn. In 1978, Sun's Steele—then an MIT grad student visiting Stanford—translated TeX for use on MIT's mainframe computer. Suddenly, Knuth recalls, "I had 10 users, then 100. Each time it went through different levels of error. In between the 1,000th and 10,000th user, I tore up the code and started over." Knuth says he realized then that TeX wasn't just a digression, it was itself part of the vision. "I saw that this fulfilled a need in the world and so I better do it right."

A key turning point in the spread of TeX was a lecture Knuth gave before the American Mathematical Society (AMS). Barbara Beeton, a staff specialist in composition systems for AMS and a longtime official of the Portland, Ore.-based TeX User's Group, remembers the occasion: "He was invited to deliver the Josiah Willard Gibbs Lecture. Albert Einstein and John von Neumann had been among the previous speakers. Knuth talked about his new typesetting system for the first time in public." Knuth was preaching to the choir; the assembled mathematicians were familiar with how printing quality had declined. Adds Beeton: "TeX was the first composition system meant to be used by the author of an article or book" as opposed to a publishing house. Soon after, AMS became the original institutional user of TeX, employing Knuth's system to publish all of its documents and journals.

As word spread and more users took advantage of his free software (written for an academic mainframe computer but soon made available for PCs), Knuth found himself studying the history of printing to find solutions for narrow applications. Often as not, his research proved fruitless and he would have to come up with his own answer. For ceremonial invitations, he created new fonts; for musical typesetting he solved difficult alignment problems. "I had so many users," he recalls. "From wedding invitations and programs for the local symphonic orchestra to computer programs."

For nearly nine years, Knuth's foray into typography occupied him full time—pulling him away from work on the programming book that he considered his true calling. "I had to think of the endgame," he says. "How could I responsibly finish TeX and say: This is not going to change anymore? I had to work out a four-year strategy to extricate myself" and return to *The Art of Computer Programming.*

Knuth's solution: with the release of TeX version 3.0 in 1990, he declared his work complete. Disciples will have to maintain the system. Knuth says he will limit his work to repairing the rare bugs brought to his attention; with each fix he assigns one more digit to the version number so that it tends to pi (the current version is 3.14159).

One result of Knuth's decision to stop making major changes to TeX is that the TeX file format has remained unchanged. "It's the only software where you can take the file for your paper from 1985 and not have to convert it to print out the same way today," notes David Fuchs, a senior researcher with Liberate Technologies (formerly Network Computer Inc.),who was a grad student at Stanford during the development of TeX. Fuchs estimates that there are 1 million TeX users worldwide; many employ special-purpose commercial packages built around the TeX "kernel," such as LATeX (a command-oriented macro language) and TeXDoc (optimized for software documentation).

"On the downside, TeX is limited in its appeal because it's not WYSIWYG," Fuchs admits, employing the acronym for "what you see is what you get"—the standard term describing text processing software that displays formatting on screen as it will appear on the printed page. Rather than offering real-time onscreen interactivity, TeX requires a markup language typed into a document and interpreted by the computer; you see what you get only after it is in print. Despite its unintuitive user interface, TeX has developed a dedicated core of production professionals who will accept no substitute. "Why would anyone want anything else?" asks Paul Anagnostopolis, a Carlisle, Mass.-based publishers' consultant and author of TeX-based software for book composition. "A lot of people don't care about WYSIWYG."

Opus in Progress

SPENDING NINE YEARS INSTEAD OF ONE TO CREATE TEX IS the same kind of epic miscalculation that led Knuth to the monumental scale of *The Art of Computer Programming.* After earning his undergraduate degree at Case Institute (now Case Western Reserve), he was studying for his PhD and teaching at the California Institute of Technology in 1962 when he was contracted by textbook publisher Addison-Wesley to write a volume on computer compilers. (Compilers are special programs that convert the text typed in by programmers into instructions in a computer's native binary language.)

In his book-lined study, Knuth recounts the history of the project. From 1962 to 1966, he wrote the first draft in pencil. The manuscript was 3,000 pages long. "I was thinking it was one volume of maybe 600 pages. I just figured type in books was smaller than my handwriting. Then I typed up chapter one and by itself it was 450 pages. I sent it to the publisher and they said: Don, do you have any idea how long your book will be?"

Faced with such an unwieldy manuscript, many publishers would have dumped the project. Instead, Addison-Wesley worked out a publication schedule for what could eventually stretch out to seven volumes. Volume 4 is supposed to be ready in 2004 and Volume 5 by 2009. Then Knuth may finish Volumes 6 and 7—if what he has to say on his chosen topics is still instructive. Peter Gordon, publishing partner at Addison-Wesley and Donald Knuth's editor for the last 20 years, explains that the success of the first three volumes of *The Art of Computer Programming* has allowed the publisher to build its entire computer science line around Knuth's work. "Don has his own life plan and his own sense of timing," he notes. "He's such a creative and gifted author, the best any editor can do is stay out of his way and let him follow his plan."

It helps that the book continues to draw praise from other seers in the digital realm. In his syndicated newspaper column, Bill Gates once responded to a reader: "If you think you're a really good programmer, or if you want to challenge your knowledge, read *The Art of Computer Programming*, by Donald Knuth." Gates described his own encounter with the book: "It took incredible discipline, and several months, for me to read it. I studied 20 pages, put it away for a week, and came back for another 20 pages. If somebody is so brash that they think they know everything, Knuth will help them understand that the world is deep and complicated. If you can read the whole thing, send me a resume."

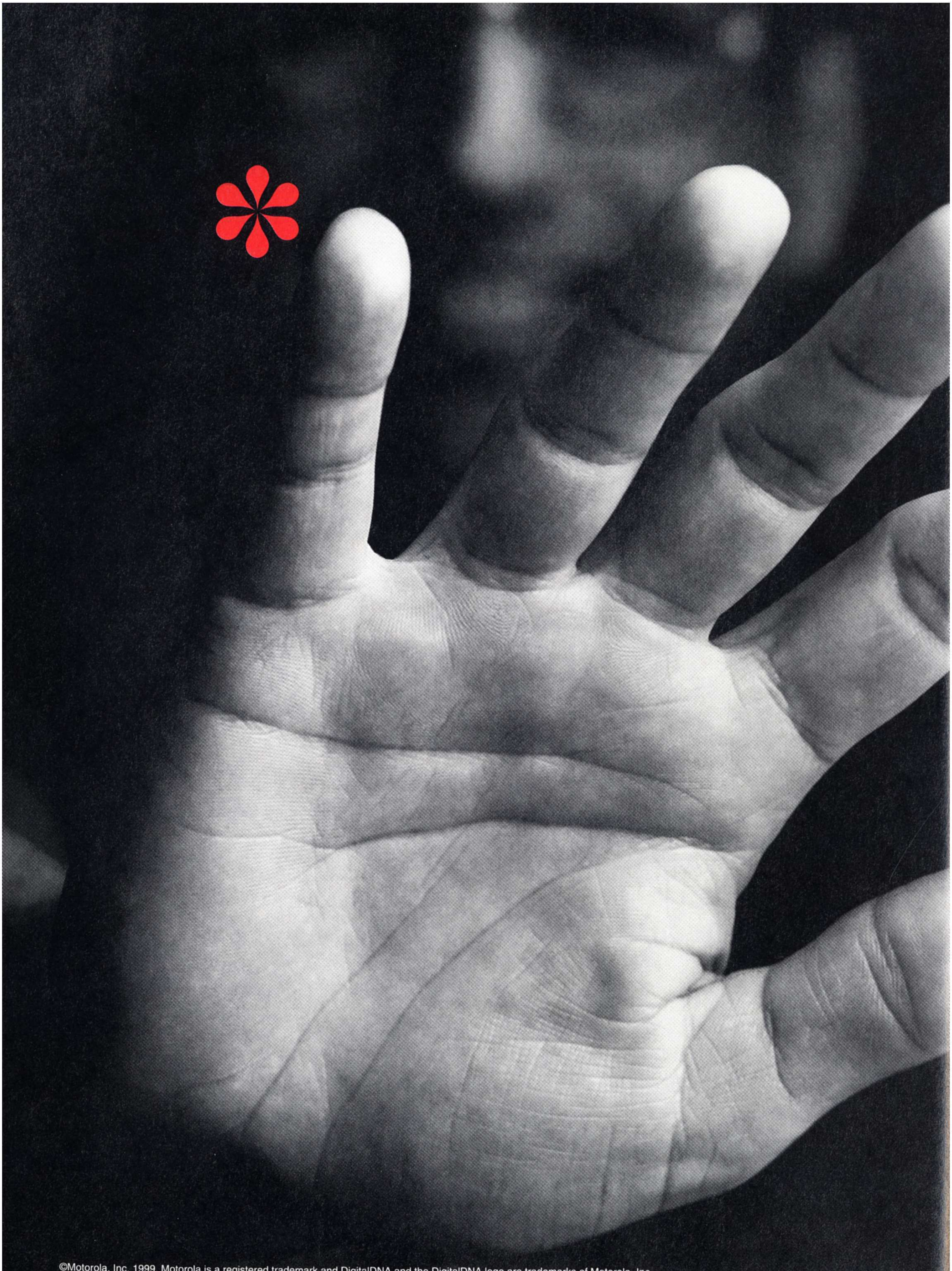
What sustains Knuth through his epic project is his fundamental love of the subject. "People who work on the analysis of algorithms have double happiness," he says, sounding Yoda-like. "You are happy when you solve a problem and again when people smile using your solution in their software."

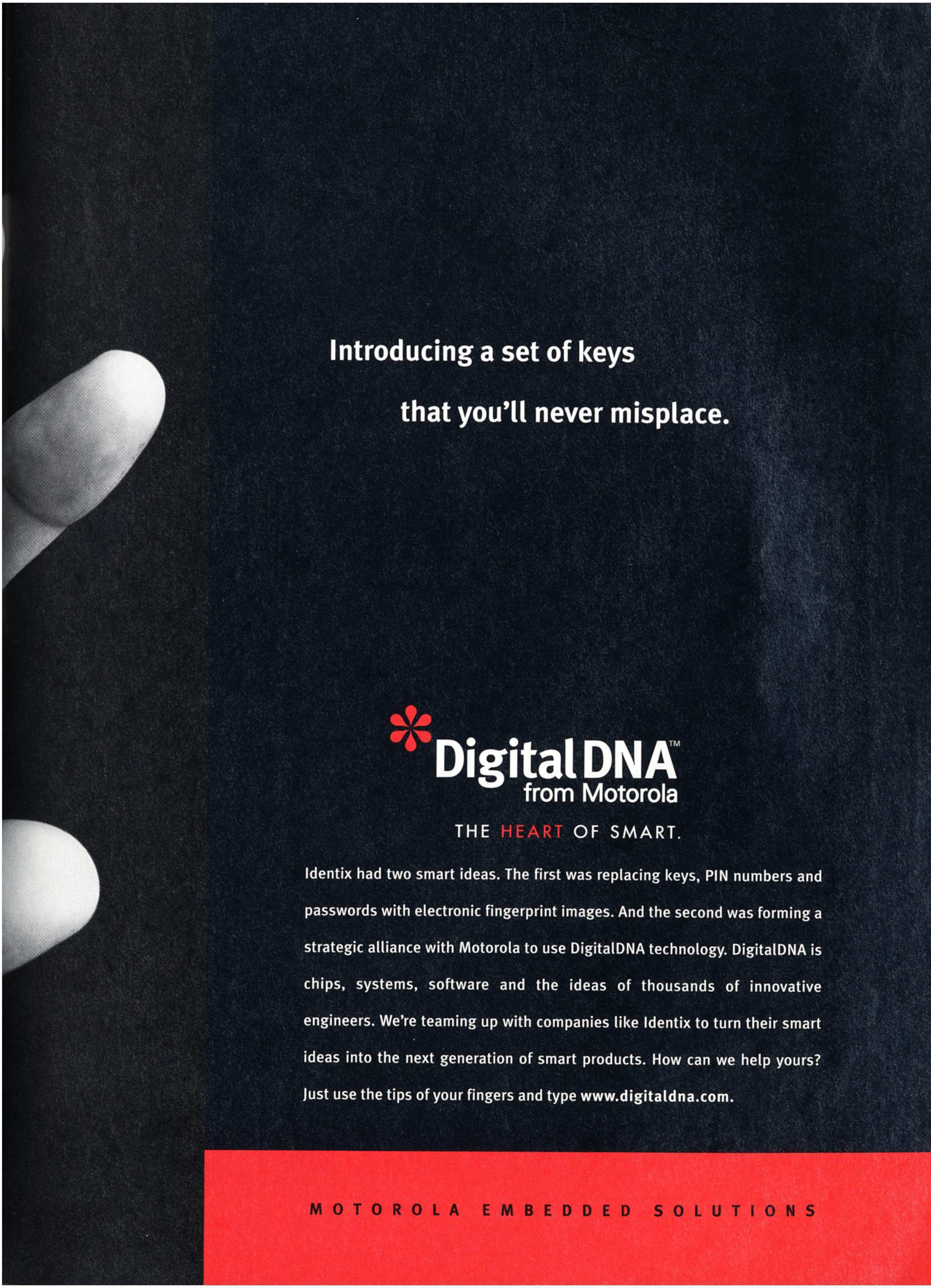
Before he can rest in the promised land, Knuth faces one last mountain. He must redesign the generalized computer used in his book for programming examples and exercises from a 50-year-old von Neumann-style machine with inefficient commands to a more modern RISC (reduced instruction set computer) system permitting faster operation. (Intel processors in most PCs are of the older variety; PowerPC chips in recent Macintosh models are RISC.) "I'm trying to design it so it's 10 years ahead of its time," says Knuth. "I've studied all the machines we have now and tried to take their nicest features and put them all together." This super RISC machine, which he calls MMIX, is essentially a teaching concept. But he says he "would love to see it built. I'm spending a lot of time documenting it so someone could build it. The design will be in the public domain." In the midst of his "Computer Musings" series of introductory talks on MMIX, Knuth is mere months away from completing this phase of his work.

And then? "I start charging away on Volume 4 at top speed. I can write about one publishable page a day," he says. On another book he once wrote at a rate of two pages a day "but that was too much. I couldn't be a good husband and a good father and that was not good. So, I'm just promising 250 pages a year for Volume 4." For devotees of Knuth's software Bible, Bill Gates included, those pages can't come soon enough.

As for Knuth's unwavering confidence in pursuing his long-term goal, biology seems to be on his side. His mother is 87, in good health—still working, he says, in real estate office management. His father, who started him on the path to computer typography, died at 62. Still, this digital patriarch concludes: "My father's father lived to be 97, so I'm hoping to take after him."

Before he does reach the advanced age required to complete all his publishing plans, Knuth may have to face the temptations that come with fame. A two-page magazine ad for fatbrain.com proclaims, over an edgy collage: "Presenting the only bookstore on earth where Donald Knuth outsells John Grisham a billion to one." This may be the first commercial acknowledgment of Knuth's iconic status among the digerati. Will such recognition lead to a plague of attention just when the sage of software is about to resume his journey toward completion of his life's mission? It makes you wonder how much longer Moses might have wandered the desert had today's media been around. ◊




Introducing a set of keys
that you'll never misplace.
DigitalDNA™
from Motorola
THE HEART OF SMART.
Identix had two smart ideas. The first was replacing keys, PIN numbers and passwords with electronic fingerprint images. And the second was forming a strategic alliance with Motorola to use DigitalDNA technology. DigitalDNA is chips, systems, software and the ideas of thousands of innovative engineers. We're teaming up with companies like Identix to turn their smart ideas into the next generation of smart products. How can we help yours? Just use the tips of your fingers and type www.digitaldna.com.
MOTOROLA EMBEDDED SOLUTIONS

May the Micro Force Be With You

After a decade of hype, microscopic mechanical systems are poised to make major changes in the size of our cell phones, the reliability of our communication systems—even the way "Star Wars" is shown.

BY IVAN AMATO PHOTOGRAPHS BY FELICE FRANKEL

LAST DECEMBER, A TEAM OF MANAGERS, SCIENTISTS AND technicians from Texas Instruments (TI) trekked from their corporate research labs in Dallas to a meeting at George Lucas' sprawling ranch in the hills west of San Rafael, Calif. Lucas was present. So was Rick McCallum, producer of "Star Wars: Episode I—The Phantom Menace," then still half a year from opening day. The movie moguls had summoned the TI staffers to audition a digital projector, built by the company, that could change how movies are shown, replacing Hollywood's beloved canisters of film with semiconductor chips.

Lucas was impressed. He called back the TI scientists. "He asked if we were interested in unveiling the digital cinema projection system at a second opening of 'Phantom Menace,'" recalls Larry Hornbeck, a soft-spoken TI physicist who has been working for the past 20 years on the digital micromirror device (DMD) that is at the heart of the new projector.

The rest is cinematic history. In mid-June, a month after the opening of "Phantom Menace" drew millions of fans, the much-anticipated movie debuted a second time at a theater outside Los Angeles and one just across the Hudson from Manhattan. Unlike the initial opening in May, however, not a frame of film snaked through the projectors. Instead, a 360-gigabyte digital file stored on 20 hard disks fed the special TI projectors lighting up the big screen.

Making it all possible was a microelectromechanical system (MEMS) featuring millions of mirrors—each roughly the size of one cell in the human body. Transistors adjust each mirror individually to one of two possible angles. Set one way, light from a projection bulb reflects from the micromirror through a set of focusing lenses and onward to the screen; tilted the other way, the light dumps into an absorber inside the projector. It's akin to a sports arena filled with millions of fans holding cards they can flip in perfect unison to construct an enormous image. Only with the TI projector, the high-resolution pictures can change every 5 microseconds (far faster than the eye can discern). By using sophisticated software and alternating beams of red, green and blue light, the system can produce more than 1 billion colors—plenty even for Lucas' cinematic fantasies.

A Star Is Born

THE SPECIAL SCREENING OF "STAR WARS" MAY OR MAY NOT HAVE served as a preview to Hollywood's filmless future (Lucas also chose a competing digital projection technology developed by CineComm Digital Cinema to show the movie at a separate pair of theaters). But it's the most glamorous sign to date that MEMS devices, often too small to be seen by the human eye, are poised to change everything from how we watch movies to the size of the cell phones we carry.

The miniature silicon machines move and work, unlike semiconductor chips used in microelectronics, in ways remarkably reminscent of macroscopic objects. And, after decades of development and hundreds of millions of dollars in investments, the micro-sequel to the original machine revolution is gaining momentum. Dot-sized motion sensors are now used in most automotive air bags, and ultrathin silicon membranes are used to measure blood pressure inside human hearts; coming attractions will feature tiny mirrors that can switch light between optical fibers to greatly enhance the efficiency and reliability of optical communications, and resonators that could shrink wireless communication, making Dick Tracy's wrist phones a reality.

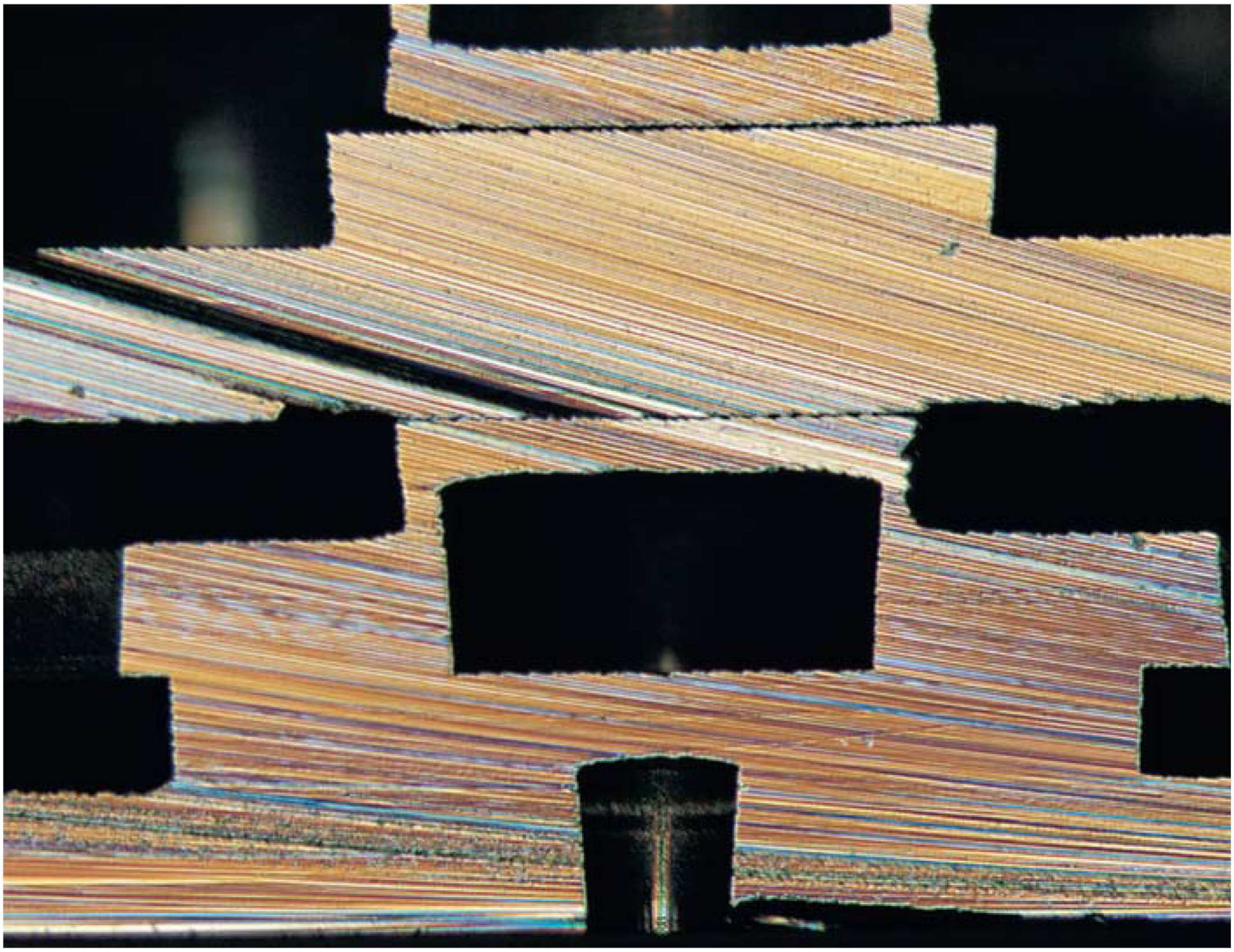
"The technology has methodically advanced during the last 10 to 15 years, and it's just hitting its commercial stride," says MEMS researcher and entrepreneur Mehran Mehregany of Case Western Reserve University. Market analyses put MEMS annual sales at several billion dollars and predict the number will grow to between $5 billion and $10 billion within five years.

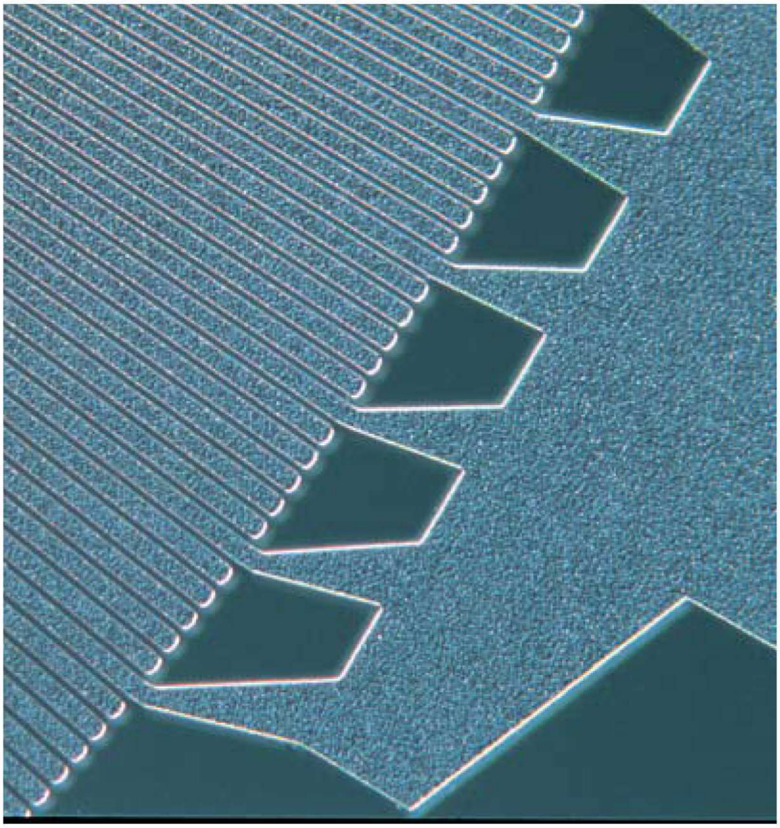
Those numbers have helped create a gold-rush mentality among researchers—and some investors. There are an estimated 10,000 scientists working on MEMS at 600 universities, government labs, big companies and tiny startups, according to Roger Grace, a San Francisco-based consultant. Fueling the fever are tales of MEMS startups striking it rich. Most notably, in 1997 data storage giant Seagate Technology bought San Jose, Calif.-based Quinta for $325 million. The startup, founded just two years earlier following a Silicon Valley cafe meeting, is developing a system using micromirrors—somewhat similar to Hornbeck's—in a laser guidance system for next-generation disk drives.

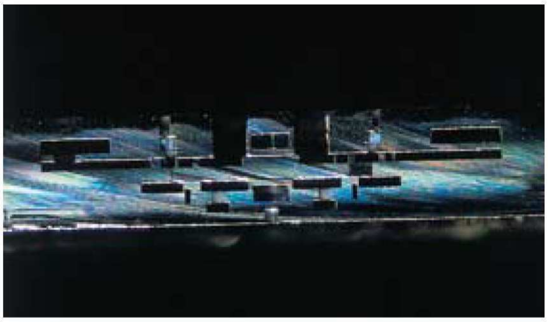
The miniature machines move in ways reminiscent of macroscopic objects. And this micro-sequel to the original machine revolution is gaining momentum.

Alongside the enthusiasm, MEMS has gained a reputation as a technology better suited to building tiny playthings than to constructing moneymaking machines. In the early 1980s, researchers first realized silicon chips could be as good for making very small mechanical parts as they were for making electronic circuits. Scientists began developing microfabrication techniques to make Lilliputian wheels and gear trains, motors that could push shafts, valves for controlling microflows of fluid, and mirrors that pop up into the path of a laser beam. But MEMS labs retained the aura of high-tech curio shops most memorable for showcasing the world's smallest versions of everything from guitars to cars. "There was too much gimmicky press," acknowledges Karen Markus, vice president of Cronos Integrated Microsystems in Research Triangle Park, N.C.

While microscopic pictures of mites and ants towering over clockwork-like structures are irresistible to journalists, some







Micropower: MIT scientists are building components of a microturbine that could eventually be used to generate electricity. Top and right show a cross-section of a 5-layer, silicon-based microturbine rotor that is designed to spin at more than one million revolutions per minute. The base of the rotor is 4 millimeters in diameter. *Researchers: C-C Lin, R. Ghodssi, A.A. Ayon, S. Jacobson, R. Khanna, M. A. Schmidt and A. Epstein.* Left is a stator that could be used in combination with the microrotor to generate electric power. Each prong is 70 micrometers long. *Researchers: R.Ghodssi, S. F. Nagle, I. G. Frechett, X. Zhang, S.D. Senturia, M.A. Schmidt and J. H. Lang.*

venture capitalists find them distinctly resistible. "My feeling is that most MEMS work is ill-conceived," says Greg Blonder, a former MEMS researcher turned venture capitalist, or as he calls himself, "entrepreneur in residence," at AT&T Ventures in Basking Ridge, N.J. Blonder contends that many examples of MEMS amount to little more than miniature Rube-Goldberg machines, and he says that MEMS projects are often answers searching for problems that have far simpler solutions. Says Blonder: These projects "add no real value but add complexity."

But that doesn't mean Blonder dismisses all MEMS projects. He simply argues that MEMS devices must be conceived of differently than macroscopic machinery. MEMS operate on a scale of micrometers and millimeters, and in that small world things can behave somewhat differently. There are surprising scaling effects—these effects, for example, allow ants to lift up to 50 times their own weight. "Where the real excitement is going to be is in MEMS that leverage the strengths of physics of those dimensions," Blonder says. Sensors, relays and other micromechanical devices capable of using extremely slight pressure and temperature fluctuations to move parts are promising, he adds. So are devices in which small sizes can speed up chemical reactions and more efficiently dissipate heat.

Blonder's cautious, discriminating approach has done little to dampen enthusiasm among researchers. The success that semiconductor chipmakers have had in shrinking microelectronics serves as an omnipresent reminder that smaller is better—and more lucrative. Microelectronics prove that you can change society on a large scale through miniaturization, mass production and cost reduction, argues Neal Barbour of Draper Laboratories in Cambridge, Mass. In his view, microprocessors and memory chips are mere hints of a much more generalized trend of miniaturizing technologies. "MEMS is fundamental, just like electronics," says Al Pisano, director of the Defense Advanced Research Projects Agency's MEMS funding program, which has an annual budget of $50 million. "MEMS will grow just like electronics. And it will become just as ubiquitous."

The use of standard fabrication tools adapted from the semiconductor industry means you can turn out micromachines as cheaply as semiconductor chips.

Cheap as Chips

ONE REASON FOR THE EXCITEMENT IS THAT WHILE MICROELECTRONICS semiconductor chips are great at logic and memory, they are a brain without a body. "Computers think and think and think. But MEMS are becoming the eyes, ears, noses, mouths, hands and feet of computers," says Markus. Adds Barbour: "All of the electronic components end up passive, but MEMS can respond to all kinds of inputs—chemical, light, heat, pressure, vibration, acceleration—all of the things that just about everybody needs to measure in just about every physical system that we have."

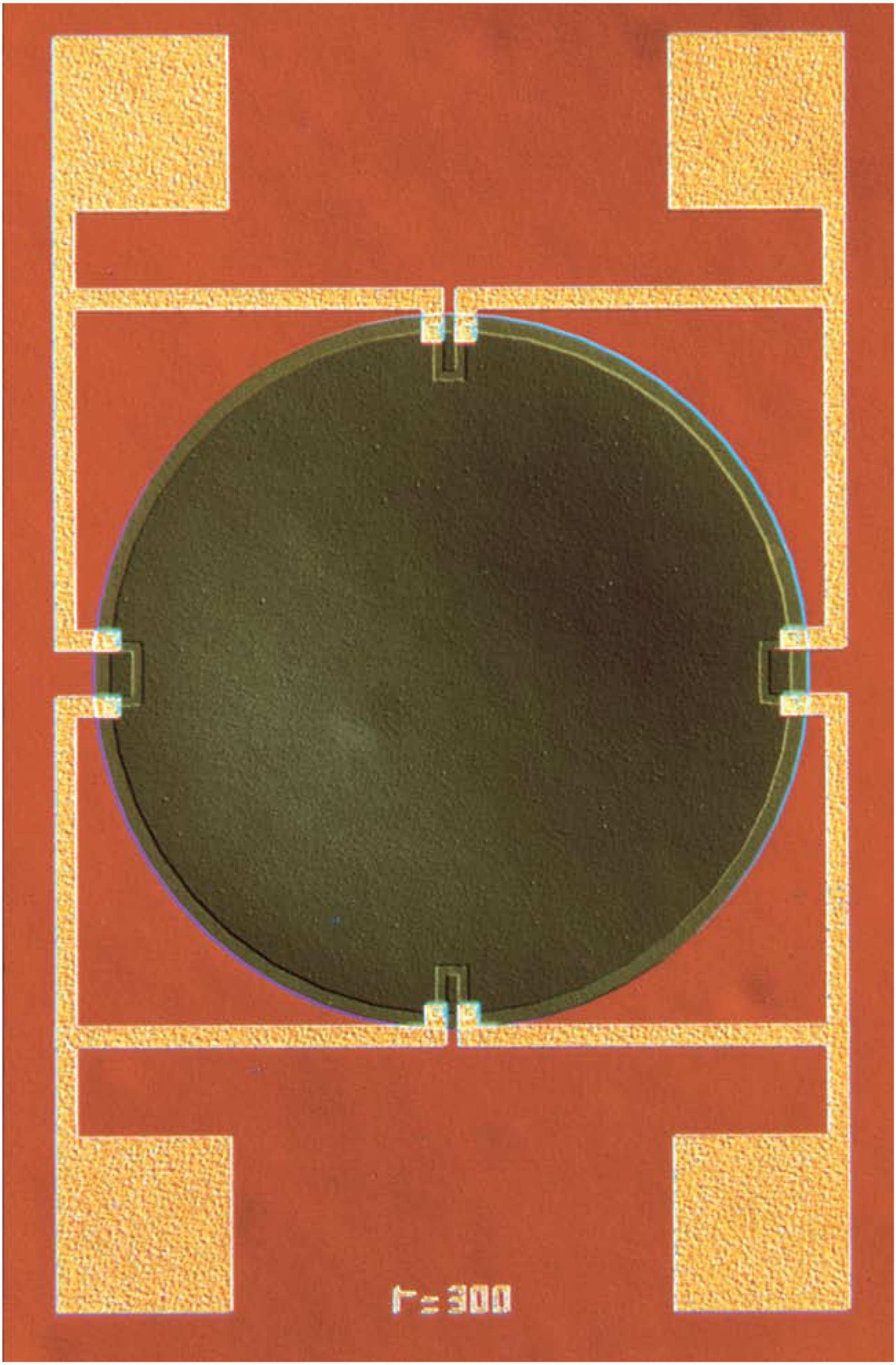
These advantages of MEMS would be enough to entice researchers, but not enough to get MEMS devices onto the market. Yet another factor has also entered the picture: These systems are no longer exotic items that take microengineering specialists months to fabricate. TI's micromirror arrays are, for example, made using lithographic techniques adapted from the microelectronics industry. Technicians start with silicon wafers, spin on thin coatings of polymer photoresists (a photosensitive material), expose plots of the photoresist to light through a stencil-like mask, and wash away the exposed photoresist to reveal a pattern of the underlying wafer that matches the pattern on the mask. After they expose the naked wafer surface, MEMS makers then etch into, around and underneath the surface, diffuse ions into the silicon, or deposit materials such as aluminum onto it. Clever sequences of masks, etching and deposition yield tiny 3-D structures that move on command.

Make no mistake: It's still not easy. But the reliance on standard fabrication tools means manufacturing technology is already in place and, once you design a MEMS device, you can potentially turn them out as cheaply as semiconductor chips. At Analog Devices, headquartered in Norwood, Mass., some 1 million tiny accelerometers are fabricated every month, according to Jeffrey Swift, director of engineering for the company's micromachined products. Buy a car today, and there's almost a 50-50 chance that one of Analog Devices' accelerometer-based sensors (each about the size of the period at the end of this sentence) will be inside the air bag systems.

Prior to micromachined accelerometers, motion sensors in air bags required up to five fist-sized components, each costing about $18. Analog Devices and several competitors sell MEMS accelerometers for less than $10 apiece, reflecting the companies' ability to make them in huge batches. The accelerometers are relatively simple—suspended rectangular slabs of silicon with fingers extending out to form what looks like a double-sided comb. The fingers of these combs mesh with silicon fingers machined into the surrounding silicon framework. The normal motion of a car, as well as the violent and jerky motion during the split second of a crash, instantly sets the suspended accelerometer in motion. The overlapping areas of the meshed silicon fingers change, which causes instantaneous changes in the structure's electrical capacitance. Those electrical changes then feed into circuitry programmed to discern potentially deadly crashes from potholes; when appropriate, the circuitry triggers the release of the air bag.

Analog Devices' engineers are developing MEMS for other emerging automotive applications such as side-impact air bags. And Swift, a father of three boys, including a new driver, suggests another possibility: "What if you had a sensor in the car that your teenager was driving that would tell you how many g forces the car experienced? Did he peel out or do a harsh stop or go around corners at really high speeds?"

Feeling the pressure: A tiny sensor built at MIT uses a silicon diaphragm 600 micrometers in diameter and contains 4 integrated piezo-resistors for converting pressure into an electrical signal. *Researchers: Lalitha Parameswaran and Martin Schmidt.*


r=300

Silicon Forests

IN FACT THE SUCCESS OF MEMS MAY DEPEND MORE ON ENGINEERS being able to think up new uses for them than it does on the skill of microfabrication labs. Kurt Petersen, widely considered one of the fathers of MEMS because of a seminal paper he wrote in 1980 at IBM Research in San Jose, Calif., is, for one, focusing his energy on Cepheid, which he co-founded three years ago in Sunnyvale, Calif. "Our role in life is DNA analysis," says Petersen. And he's convinced MEMS are going to prove useful.

One of the most time-consuming and least automated tasks of DNA analysis is the preparation of specimens—extracting, concentrating and purifying the genetic material so that it can be copied and sequenced. "People have not been able to extract and purify DNA on a microscale," points out Petersen. Enter MEMS. Using a technique called deep reactive ion etching, in which ions chew straight down into exposed areas of a silicon wafer (as opposed to the surface micromachining used to make Texas Instruments' tiny micromirrors and Analog Devices' accelerometers), Petersen and his colleagues have created microfluidic chambers to capture and concentrate DNA and RNA. One design consists of a square array of 1,600 pillars, each 10 micrometers in diameter and 10 micrometers from its neighbors; as biological samples flow through this forest of silicon, DNA (or RNA) sticks to the pillars. The captured nucleic acid can later be released by an appropriate buffer; once separated, DNA travels through an exit port to downstream modules for analysis.

Cepheid expects to market a handheld instrument that can accept virtually any biological sample, extract its DNA, and then amplify and detect nucleic acids previously identified to be of interest. Cancer screening, as well as detection of pathogens and biological warfare agents, is among the applications. Full commercialization is expected in several years.

Guiding Light

CANCER DIAGNOSIS IS SERIOUS STUFF AND ENORMOUSLY IMPORtant. But other uses for MEMS are lighter at heart. At the University of Michigan's MEMS research center, Clark T. Nguyen envisions a Dick Tracy future based on MEMS resonators and frequency filters for cell phones and other communications gadgets. These are the components that ensure transmission takes place at specific frequencies and allow receivers to tune into particular frequencies plucked from the cacophony filling the airwaves. Unlike the pinkie-nail-sized quartz crystal resonators used in cell phones, whose oscillations are in the form of mechanical waves traveling back and forth along the solid crystal's atomic framework, MEMS resonators have moving parts more akin to pendulums. Yet thousands could fit into the same space taken up by one of their crystal rivals.

As researchers like Nguyen miniaturize radio frequency components for cell phones, pagers, Global Positioning System receivers and other technologies, devices can become more selective in the frequencies they receive or transmit. Such selectivity means they require less power. "We are looking at a process that can take the whole cell phone and fit it onto a wristwatch, or a ring on your finger," Nguyen says.

Others predict they are on the verge of using MEMS to transform the communication infrastructure based on optical fibers and other light-based technologies. Considering that the light-carrying core of optical fibers is about 9 micrometers in diameter, it's no surprise that systems engineers at places like Lucent Technologies would look to diminutive devices to help them steer light through fiber networks. "We believe MEMS is going to really revolutionize how photonic switching gets done," says David Bishop, head of microstructure physics research at Lucent's Bell Laboratories in Murray Hill, N.J. Some of the first of these microswitches for light could show up in the communication network in the next year or so, says Bishop.

"For the moment, optical switches are heavy and expensive pieces of equipment," explains Bishop. "Some involve just taking the end of a fiber, connecting it to a motor and you move it [from one fiber to another] that way." Instead of moving the fibers, MEMS promises more elegant, cheap and reliable ways of optical switching using tiny mirrors and lenses—in other words, by guiding the light. "The nice thing about photons is they are small and don't weigh much, so you can use a micromachine to move them around," says Bishop.

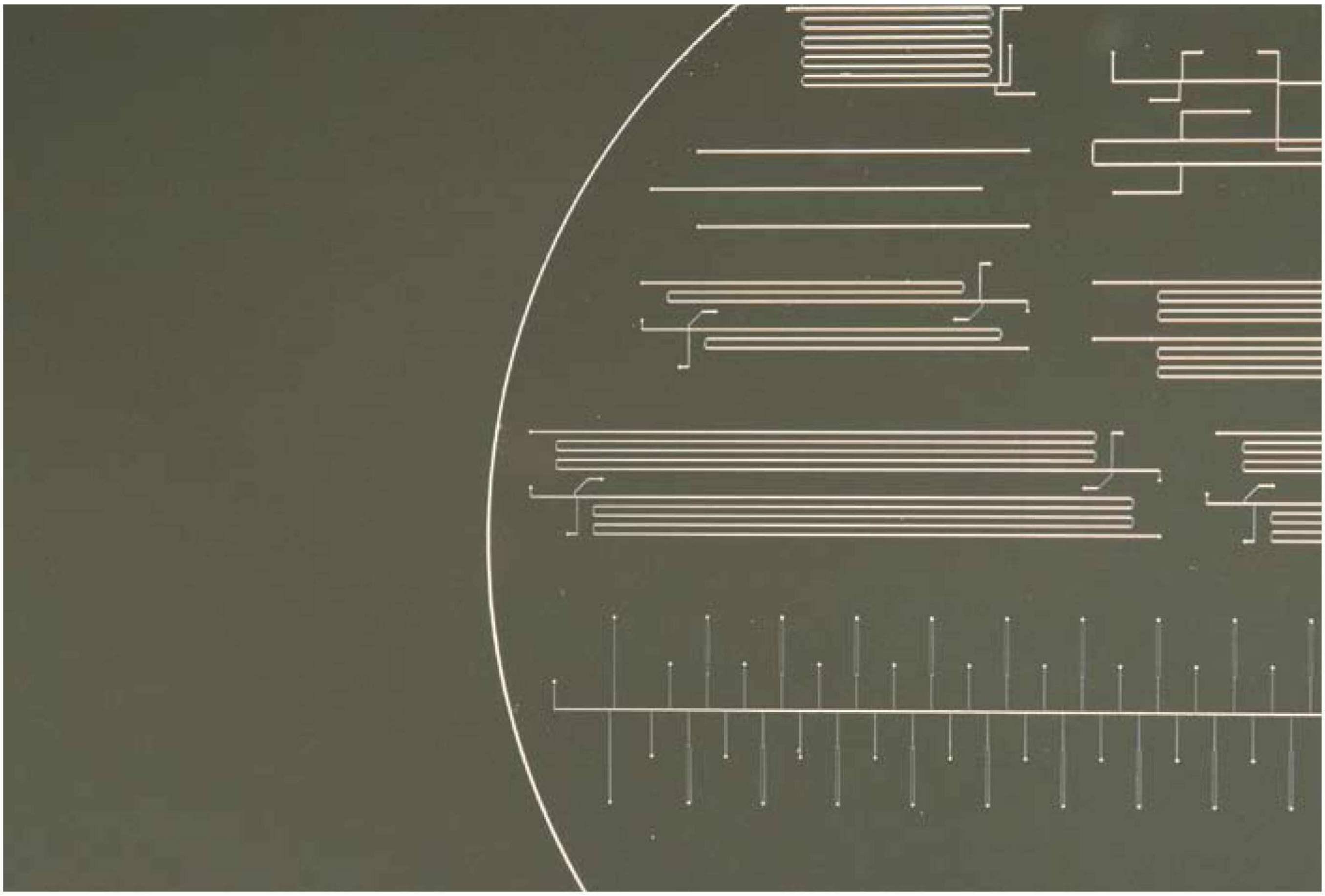
Miniaturized radio frequency components could make it possible to shrink a whole cell phone so that it fits onto a wristwatch, or a ring on your finger.

In one MEMS design, Bishop and colleagues have fabricated a "thermally deformable micromirror" that can change its focal distance. Smaller than a poppy seed, it looks like a radar dish with eight individually tiltable triangular wedges (each made of gold-coated silicon). With this design, light coming from eight fibers can be precisely recombined (multiplexed) into downstream fibers positioned at several of the adjustable mirrors' focal points.

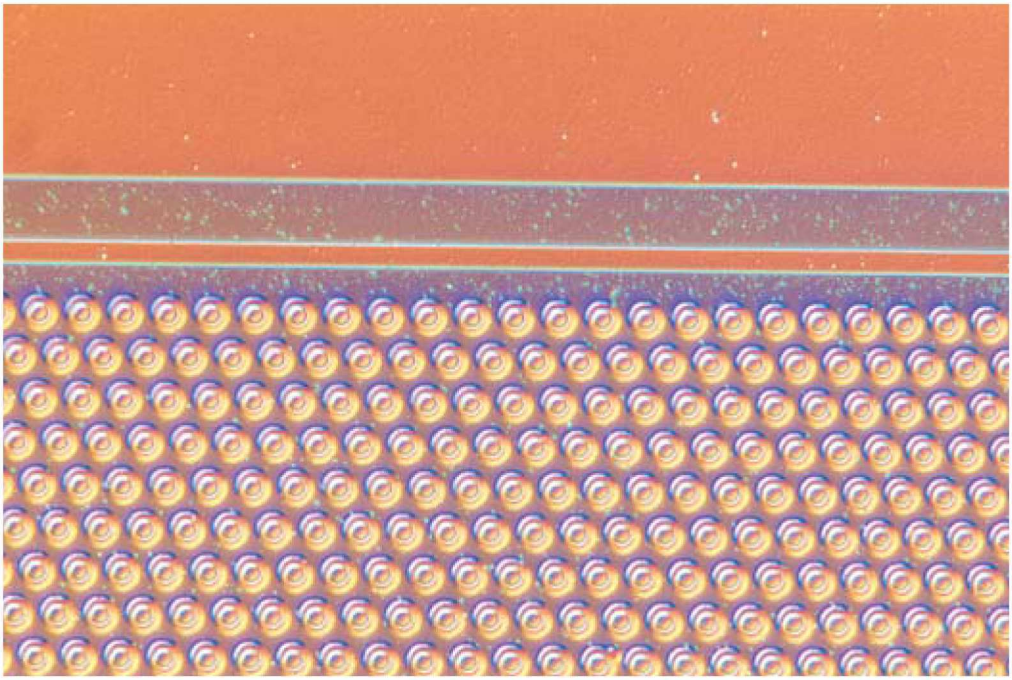
Devices like these could help reduce the vulnerability of photonic networks to failure. If an optical fiber gets severed in the middle of the night, explains Bishop, you would like to be able to reconfigure the path of light in that network without having to send a truck out to fix the fiber. As Bishop sees it, pressing a button that sends a little jolt of light or electricity to the invisible wires of a poppy-seed-sized mirror might be all it will take to reroute the light and keep the lines open.

Spinning Ideas

IF THE DELICATE MANIPULATION OF DNA AND PHOTONS SEEMS a likely match for tiny machines, consider the research going on at the gas turbine laboratory at MIT. This is home to engineers expert on the multi-ton turbines and jet engines that have powered industry for decades. But these days it is also home to one of the most promising new twists in tiny machines—power MEMS. What if you could use the energy from tiny



BioMEMS: Scientists at the Whitehead Institute are using channels micromachined onto a silicon wafer for DNA separations. They inject the various channel designs with a high-molecular-weight polymer that serves as a sieving matrix; they then apply an electric field that directs DNA samples though the channels. The devices work 10 to 100 times faster than conventional DNA separation techniques. *Researcher: Dan Ehrlich.*



Tiny stretch: To purify hydrogen, chemical engineers at MIT microfabricate a multilayered membrane between two channels etched in silicon. Each of the circles, which are 4 micrometers across, is a perforation in a layer of silicon nitride and of silicon oxide; gas flows from the top channel through these holes to a palladium thin film, through which hydrogen—but not other gases—can diffuse to the bottom channel.
Researchers: Klaus Jensen, Alex Franz, Martin Schmidt.

combustion chambers to drive microturbines and microgenerators? Or if you could build rocket engines the size of a coat button?

A group of several dozen MIT scientists are trying to do just that. One project involves building a microjet that runs on hydrogen and that could be used to power a 15-centimeter-long airplane. "The whole idea was somewhere between silly and fantastic when we started about 10 years ago," says Alan Epstein, director of the Institute's gas turbine lab and one of the originators of the power MEMS effort. "But we ran the numbers. They said this could work." Since then, Epstein and his collaborators at MIT and elsewhere have chipped away at many of the necessary parts—little fuel injectors, combustion chambers and silicon microturbines that look something like high-tech pinwheels. Says Epstein: "This is not vaporware."

The microjets could end up becoming part of a fleet of surveillance air vehicles several inches long that military planners would like to see in their bag of intelligence tricks. But the implications of power MEMS go far beyond that—it could solve a fundamental challenge facing engineers as they try to build smaller and smaller devices: How do you power them? Conventional batteries have not kept pace with the miniaturization trend. "The most important economic possibility is to use these little engines like batteries," suggests Epstein.

Just as power companies use massive gas turbines to drive electrical generators, Epstein says microturbine gas engines could become an alternative to batteries for supplying portable power. In a package of a few cubic centimeters, he says, a microturbine fueled by a tiny aluminum tank of hydrocarbon fuel could supply 20 or 30 times the energy of a conventional battery. Laptop computers could start feeling more like pads of paper and cell phones could last weeks without needing to be rejuiced. Such a MEMS power source is still at least several years off. But, says Epstein, "we're convinced it can work."

What if you could use the energy from tiny combustion chambers to drive microgenerators? It could mean an alternative to conventional batteries.

Battery manufacturers like Duracell may not need to look over their shoulders—at least not yet. But the progress of Epstein's microturbines from theoretical musings a decade ago to prototypes today shows that once-arcane MEMS projects could end up transforming even a multibillion-dollar business like batteries. And the ambition of Epstein and his colleagues at MIT to use tiny spinning turbines to power the next machine revolution shows just how strong an impact MEMS has already made on the engineering mindscape.

How fast the revolution of tiny silicon machines will take to change the technology that we all use and rely on is still anyone's guess. But if George Lucas could make a squat little robot into a worldwide movie star, he—and thousands of scientists—just may be able to help do the same for microscopic machines. Only this time, it's not science fiction. ◊

MEMS Mania: A Sampler

COMPANY	GOAL	STATUS
Analog Devices	Micromachined accelerometers and actuators	Commercial products
BF Goodrich	Aerospace sensors	Research
Caliper Technologies (1995 startup: Mountain View, CA)	Lab-on-a-chip for microscopic fluid handling	Commercial products
Cepheid (1996 startup; Sunnyvale, CA)	Micro-chips for processing of DNA samples	Commercial products
Goodyear Tire	Intelligent tires that sense pressure	Prototypes
Hewlett-Packard	High-capacity data storage	Research
Honeywell	Polymer actuators capable of affecting macroscale objects	Research
IBM	Terabit data storage devices	Research
Lucent Technologies	Components for optical communications	Prototypes
Rockwell	Radio frequency switches for communication systems	Research
Seagate Technology	Optical-based data storage devices	Prototypes
Texas Instruments	Digital projection systems	Commercial
TRW	Digital propulsion for micro-satellites	Research
Xerox PARC	Microscopic controls for macroscopic systems	Research
Silicon Light Machine (1994 startup; Sunnyvale, CA)	High-resolution displays	Product development

Leading MEMS projects by industrial groups in the United States. Source: Company reports and Defense Advanced Research Projects Agency (DARPA).

The Knowledge Lab

NCR, the company that brought us the cash register and the ATM, has a glitzy new research division—funded partly by the company's customers. Will it remake technology? Or just the corporation's image?

BY MEG CARTER

PHOTOGRAPHS BY DUDLEY REED

The British aren't famous for creativity in the kitchen. But last September a London-based team of researchers struck a blow against this cultural cliché. They didn't introduce a new cuisine, however; they came up with a new kind of cooker. Dubbed the "Microwave Bank" by its creators, the prototype looked much like a standard countertop microwave, with one big difference: a computer screen where the door window ought to be. Voice recognition software and touch-screen technology allowed users to send e-mail, pay bills, access their bank accounts or watch TV. A built-in barcode scanner automatically added items to an electronic grocery list. Resident intelligent agents kept track of a user's domestic habits and then suggested dishes or looked up recipes online. And it even cooked food.

The launch of the Microwave Bank drew an impressive amount of attention from the UK press, and marked the very public debut of the prototype's developer, the Knowledge Lab. Set up in September 1996 by the Financial Solutions Group of Dayton, Ohio-based NCR—the world's leading supplier of ATMs—the Knowledge Lab boasts an eclectic mix of twenty- and thirty-something staffers. Computer scientist works alongside technical engineer, artist, jewelry designer, graphics/industrial designer, biophysicist, mathematician, economist, psychologist and philosopher. The 25-member team's mission is broad: focus on tomorrow's consumer. Or, as the Knowledge Lab's glossy launch brochure declared: "To create foresight—to get a grasp of the future before it happens. To start to lead the way in challenging established assumptions." Housed in a stylish open-plan studio space in central London, the lab is separated from Financial Solutions' reception by a wall of frosted glass, perforated with portholes to give visitors a glimpse of this future.

Forward thinking: Research fellow Sarah Woods led the Knowledge Lab team that developed the Microwave Bank.

The Knowledge Lab's director, neuroscientist Stephen Emmott, sums up the lab's fundamental focus within the rather loose bounds set by its parent company with two words: relationship technology. "The context for everything we do is the networked economy," Emmott says, "and the central purpose of networks is to establish and maintain relationships."

The relationships that interest Emmott and his lab are those between consumer and consumer and between consumer and supplier—the demands and preferences of the consumer and how the supplier serves and stimulates these demands. By exploring and exploiting these relationships, NCR hopes to find ways to reposition itself after a troubled time in the 115-year-old company's history. And in setting up the lab, NCR has forged unusual relationships of its own, recruiting its own customers (banks) to help fund and advise the new center and even contribute their research to its projects—much as MIT's Media Lab is funded through its relationship with technology firms. The verdict is still out on how successful this project will be. While observers express praise for the lab's boldness, they also voice skepticism about the originality of some of its ideas. And some question whether the ultimate aim of the lab is more PR than R&D.

"We needed a point of difference," says the NCR executive who launched the lab. Now lab staff will have to show how different their work really is.

Only Connect!

THE TELEPHONE AND E-MAIL ARE TODAY'S QUINTESSENTIAL relationship technologies, says Emmott, who left a position as a senior scientist at Bell Laboratories to head the new London lab. "Both are used to maintain and develop relationships, although they were designed as information technology." In dreaming up the network-based relationship technologies of the future, Emmott says he and his staff want to "reach the non-computer-using consumer through 'invisible computing,'" and come up with devices and services as user-friendly and useful as the ubiquitous telephone.

That's the philosophy at the heart of the Microwave Bank, says Sarah Woods, the Knowledge Lab research fellow who led the project. "More than 90 percent of the UK population have a microwave, but unlike the VCR, the biggest technophobes can use it," says Woods. Employing a familiar, everyday appliance means users don't have to be an Internet Einstein to access a full range of services available on the World Wide Web, says Woods, and it "demonstrates how things can be networked around the home." She and her colleagues are also working on the "Thinking Bin," a high-tech trashcan that would communicate with the Microwave Bank, adding discarded items to the shopping list or automatically sorting garbage for recycling.

With four (soon to be five) Knowledge Lab groups currently tackling some 30 projects *(see "Structuring Knowledge," p. 88)*, Emmott's idea of invisible computing extends well beyond the kitchen. There's a prototype secure system enabling micropayments and communication via either the Internet or phone using everyday objects—rings or cufflinks might serve as tokens, increasing or decreasing in monetary value when waved at a point-of-sale device or ATM.

Researchers in the lab are also focusing on ways to put a friendlier face on desktop e-commerce. "Rei," for example, is an interactive Internet soap opera that enables users to buy featured products with a click. For those looking for a collector's item or a bargain, Knowledge Lab staff are developing a system that sends a squad of intelligent agents onto the Internet to hold and participate in online auctions, roaming through sites to meet the user's criteria for buying and selling and developing strategies to optimize prices. In Emmott's words: "eBay on testosterone."

So far, 15 patents have been registered, making commercial exploitation of the Knowledge Lab's activities a rising priority for NCR. Projects such as Microwave Bank have already gone as far as they can within the lab's confines, Woods says. NCR executives plan to open a sister division whose mission will be taking Knowledge Lab concepts into production and out to market. Though the new division was scheduled for launch by the summer of 2000, its name, location, staff and structure were yet to be confirmed when *TR* went to press.

Bonding With Bankers

IF THE KNOWLEDGE LAB SUCCEEDS IN DEFINING AND designing the next wave of commerce-enabling technology, it will in many ways be a move to NCR's roots. After all, the corporation was founded in 1884 as one of the earliest cash-register manufacturers. Originally called the National Cash Register Company, NCR was for decades a leader in banking and consumer-transaction technology. But in the 1980s, NCR got big for its boots, spreading itself into a number of loosely associated businesses (there was even an NCR PC).

By the end of the 1980s, NCR had been overshadowed by younger organizations driving the personal computer revolution. Without the economies of scale that allowed upstarts such as Compaq and Dell to manufacture competitively, the company began suffering heavy losses—despite the growing importance of two core strengths: ATM and point-of-sale technology. By the mid-1990s, it was clear NCR needed to change. Moreover, the change needed to be highly visible, re-establishing NCR's reputation for innovation in the fast-paced, increasingly aggressive banking and retail marketplace.

NCR's strategy was to outsource the manufacturing of hardware such as ATMs, cash registers and barcode scanners and concentrate on the company's ability to gather data about customer transactions. At the same time, corporate restructuring moved NCR's Financial Solutions Group's headquarters to London—it was then that the Knowledge Lab was born. "We needed a point of difference," says Kicki Wallje-Lund, Financial Solutions Group vice president of business development and the NCR executive responsible for launching the Knowledge Lab. "Our competitors had state-of-the-art banking centers to show

Can he relate? Lab director Stephen Emmott focuses his division's efforts on the complicated relationships between players in a networked economy.

customers visiting their HQs. We wanted something different—to be recognized as a 'thought leader.'"

The proposed structure of the lab was intriguing: Although launched and housed by NCR, it would be co-funded by the Financial Solutions division's customers—the banks. This would not only offset some investment costs (NCR spent £3.5 million, or about $5.5 million, in the first year), Wallje-Lund explains, but also help the company forge stronger relationships with its customers. Rather than simply paying money up front for an entitlement to research results or regular reports, banks were invited to become partners (in NCR-speak, "members"). Member banks could join an advisory board and have a say in the conception and utilization of Knowledge Lab concepts. Members were invited to contribute to the lab's research by, for example, coordinating consumer trials.

Some observers question the lab's seriousness about innovation in technology. But given recent history, the parent company had to do something.

Initially, there was skepticism within NCR as to whether customers would pay, Wallje-Lund says. But the lab secured a high-profile portfolio of commercial partners, including Barclays Bank, HSBC, Sun Trust and Wells Fargo. "The level of interest exceeded our initial targets," she adds. The first year, 10 banks each contributed $25,000. This year, two dozen are contributing up to $50,000 apiece while NCR has upped its annual investment to £4 million to £5 million ($6.3 million to $7.9 million).

Indeed, the biggest challenge wasn't finding sponsors but getting the right people to work in the lab, Wallje-Lund says. "We found ourselves in a catch-22 situation: We needed to change people's perceptions about NCR if we were to convince them to come to us rather than, say, Microsoft. The trouble was, we couldn't do this until we had the right people in situ."

Luring Stephen Emmott away from Bell Labs was a key accomplishment, one that's drawing kudos from Knowledge Lab members. "He's a marvelous leader, and a visionary," gushes Roger Alexander, managing director of the emerging markets group at Barclays Bank. Alexander is confident that NCR is giving Emmott and his lab enough latitude to operate productively.

It was exactly this promise of the "freedom to innovate" that drew Emmott to the Knowledge Lab. "All they said to me was 'You can do whatever you want,'" he explains. "Of course, there was a tacit assumption that this would be relevant to technology, but the key was they did not tie me specifically to e-commerce, or even banking technology."

An Image of Innovation?

Room to grow is certainly important to the success of any young research operation, but Emmott's words taken in combination with the generally fuzzy corporate rhetoric surrounding the Knowledge Lab's mission beg the question: Is the lab more a showpiece than a hothouse for new technologies?

Michael Bove, head of the MIT Media Lab's Object-Based Media Group, is one observer who has his doubts. "There have only been a handful [of technology projects] announced so far," he notes, "and a number of these sound as if they were created to make NCR a good press release." This is not an entirely critical statement, however. Explains Bove: "Given NCR's recent history as a corporate entity, it had to do something. It's a good start."

Still, Bove questions the originality of Knowledge Lab concepts, and with good reason—his own work includes "Hyper Soap," an interactive Internet soap opera which, like "Rei," allows users to click on and buy featured products. And many manufacturers are using their research divisions to get in on the invisible-computing game: In October 1998, for example, Italy's Merloni Elettrodomestici, Europe's fourth-largest home appliances producer, unveiled a new line including washing machines, dish-

Structuring Knowledge: Groups at the Knowledge Lab

GROUP	FOCUS	RESEARCHERS' DISCIPLINES
Consumer Research	Understanding the changing relationships between banks and other commercial providers and their customers by focusing on consumers' behavior, attitudes and use of technology	Marketing Strategy Psychology Human Factors
Computational Modeling	Developing new mathematical approaches to modeling, allowing providers to predict and manage customer relationships	Biophysics Language Acquisition Statistics
User Experience	Future products at the intersection of computing, networks and everyday objects—particularly fashion and household goods—and their application to e-commerce	Design Interactive Design Furniture Design Industrial Design Fine Art Telecommunications
Emerging Technologies & Lifestyle Engineering	The convergence of computing and communications technology	Philosophy Electronic Communications Computer Graphics Machine Vision

Prominent in the foreground: Kicki Wallje-Lund, the NCR vice president who started the lab, remains a highly visible force.

washers and refrigerators that can communicate with online assistance centers and with one another. Meanwhile, UK-based Electrolux has developed "Screenfridge," complete with LCD touch screen, barcode scanner and Internet connection.

In the view of Alexander Linden, senior analyst for advanced technology applications at GartnerGroup, an international research and consulting firm, the Knowledge Lab has plenty of company. "Many companies now have similar operations in place," says Linden. "Labs have become a highly competitive area of investment for all concerned."

Bove believes that whether the Knowledge Lab turns out to be a good investment for NCR will depend partly on the parent company's expectations—"to explore new opportunities or remake the organization. If it's the former, anything they do will probably be a good thing. If, however, it's the latter—this may prove problematic."

The Knowledge Lab may get a grace period to prove its mettle, because NCR's other shifts in focus are paying off. Last year, the company reported profit of $122 million on revenues of $6.5 billion. In the fourth quarter of that year it posted revenue growth for the first time in 13 quarters and improved gross margins by 2 percent. As the bottom line fattens, Knowledge Lab lingo is creeping into its parent's way of thinking: A new mission statement, or "NCR Manifesto," outlines the company's future direction and shaped an international advertising campaign that premiered in May. "We are not a business-to-business company; we are a business-to-customer-to-consumer company," the manifesto declares. "For over a century we have been managing 'the point of transaction.' For the next 100 years, we are going beyond that point of transaction to the value and trust of relationships." The next few years will show whether the Knowledge Lab can help its parent make good on these brave words by moving beyond corporate image-making to technological innovation. ◊

Our TR100 Judges and their thoughts on innovation...

Think of something new, you've got an invention. Change the world in which we live, you've got an innovation.

Arno Penzias
Venture Partner, New Enterprise Associates; Nobel Laureate-Physics 1978

I think if you really believe in yourself, if you really stick to what you're doing, there is very little that is impossible.

Robert Langer
Kenneth J. Germeshausen Professor of Chemical and Biomedical Engineering, Harvard-MIT Division of Health Science and Technology

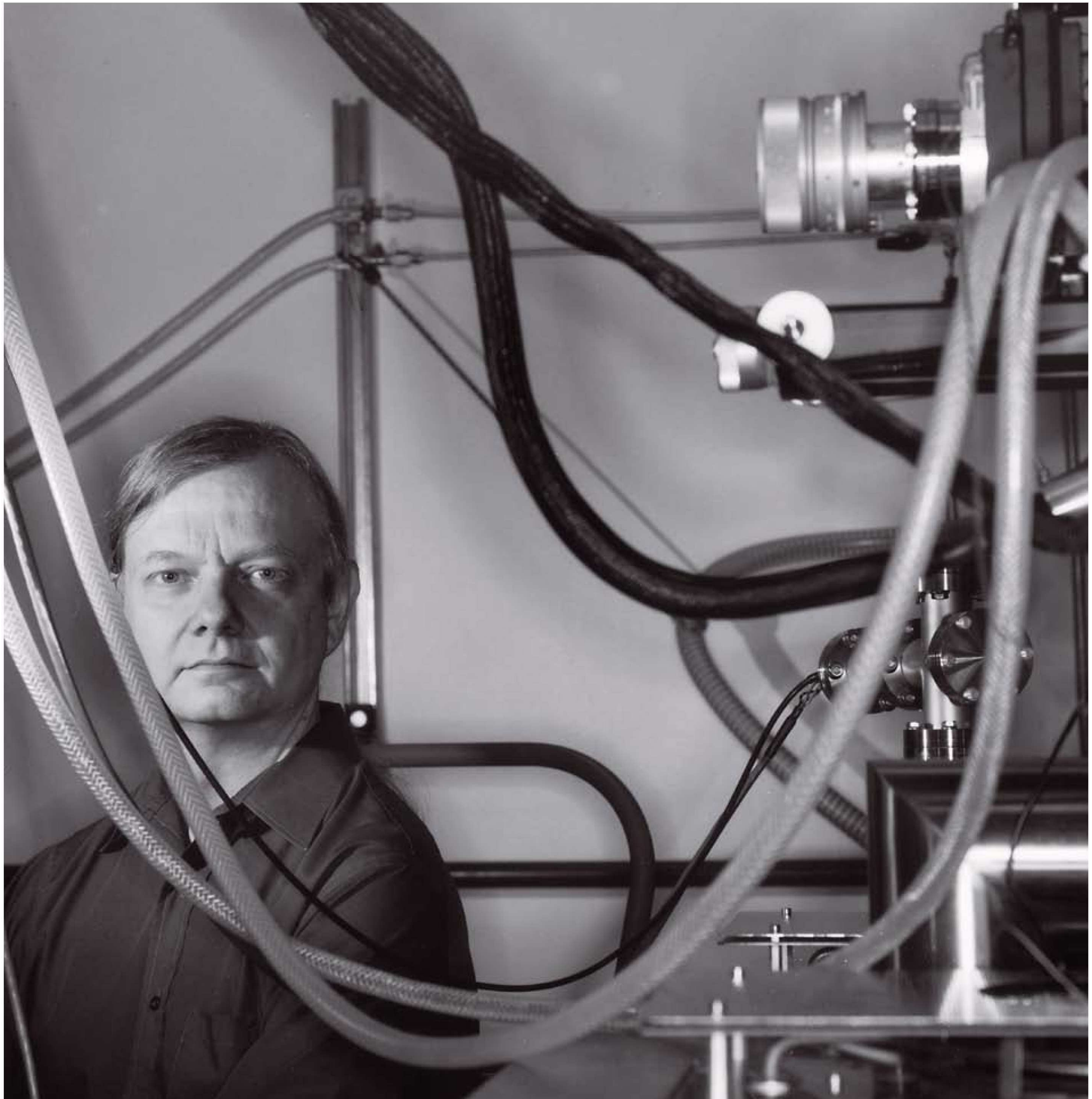
Inventing can be tricky, but selling, now that's a really complicated part of innovation.

Bob Metcalfe
Technology Pundit; Vice President, Technology,, International Data Group; Inventor, Ethernet; Founder, 3Com

Only a couple decades ago there were just a few real risk takers - the true pioneers of this amazing industry.

Ann Winblad
Partner/Co-Founder, Hummer Winblad Venture Partners

Panel of Judges:
David Baltimore
John Benditt
Al Berkeley
Anita Borg
Morris Chang
Michael Dertouzos
John Doerr
Bruce Journey
Robert Langer
Bob Metcalfe
Nicholas Negroponte
Arno Penzias
Kim Polese
Diana Garcia-Prichard
Judith Rodin
Phil Sharp
Alan Spoon
Ray Stata
Anthony Sun
Chuck Vest
Larry Weber
Ann Winblad
Wm. A. Wulf
John Yochelson



Computing After Silicon

How will computers be built in 2015? Hewlett-Packard's Stan Williams thinks he has a good recipe. It's not perfect—but that's the beauty of it.

Q & A

Four years ago, UCLA chemistry professor R. Stanley Williams and computer giant Hewlett-Packard (HP) made mid-career changes at the same time. The company had grown into one of the world's leading computer and microprocessor makers, but it still didn't have a fundamental research group. Williams had spent the previous fifteen years in academia and feared he was losing contact with the realities of the business (earlier in his career he had worked for several years at Bell Laboratories). The solution: a basic research lab at HP directed by Williams.

As head of the lab, Williams' chief concern is the future of computing. The progressive miniaturization of silicon-based integrated circuits has led to smaller, cheaper, more powerful machines. State-of-the-art chips now have features as small as several hundred nanometers across (a nanometer is a billionth of a meter). That's small. But according to Williams' calculations, the ability to continue to shrink silicon-based devices is likely to grind to a halt somewhere around 2010. Such predictions are hardly shocking—other Silicon Valley experts have reached similar conclusions. What *is* surprising is that Williams believes he and his collaborators at HP and UCLA have hit on a solution: a viable heir to silicon.

If Williams is right, computing will one day rely on nanometer-scaled components cheaply and easily assembled using simple chemistry. Instead of today's technique of precisely carving features onto

PHOTOGRAPHS BY TIMOTHY ARCHIBALD

silicon chips to create complex and near-perfect patterns, technicians will dip substrates into vats of chemicals. And if the mix is right, wires and switches will chemically assemble themselves from these materials. It would make possible tiny, inexpensive and immensely powerful computers. This is a fascinating vision. Yet, after all, Silicon Valley (and the popular press) are full of fascinating visions of the future of computing. What makes the concoctions Williams is cooking up at HP more compelling is that they're not just ideas. Last year Williams and his co-workers published a report in *Science* describing a computer architecture that could make chemically assembled circuits feasible; and this July the group published a second *Science* paper, this time describing the synthesis of a first potential component of their computer—molecular electronic switches. The results made headlines in newspapers around the country.

In the weeks before the media frenzy, *TR* Senior Editor David Rotman chatted with Williams about computing after silicon, basic research in high-tech corporations, and his own personal transition from the university to the private sector.

Companies that successfully harness nanometer-scale structures for computing and communications will be huge winners.

TR: You came to HP in 1995 to establish a basic research lab after being a professor at UCLA. What was your mission?

WILLIAMS: Hewlett-Packard never really had a basic research group. In the past, there had been discussions within HP in which people said, we really ought to be doing more basic research, we really ought to be somehow returning knowledge to the well—those kind of philosophical discussions. And there were always a few people doing some fundamental work. But HP realized that it had to create a separate group that was more isolated from the daily demands of product research to have a sustained effort. I was contacted and asked if I would be interested in trying to bootstrap up a basic research group. I firmly believed, and in fact I believe even more strongly now, that fundamental research has real value for a corporation.

TR: How do you demonstrate that value?

WILLIAMS: There are several ways. One is to provide a vision for what electronics and computing are going to look like in a 10-year time frame. We also act as a technology radar. We often hear about developments before the people in the trenches, and we can alert them that there are interesting opportunities or perhaps threats that are coming along. Also, we're working on such fundamental issues that if we do succeed the payoff for the company is going to be enormous. And they know it. Every intelligent investment portfolio has a few long shots.

TR: Have things worked out as you expected since starting up the lab?

WILLIAMS: When I came to HP, I had very nebulous ideas about the electronics of the future. Now we have a roadmap. That has been amazing. There are a couple of things that haven't worked out as I expected. I had hoped to have several joint research projects with the more applied labs. Even though the researchers themselves are interested in working with us and their managers encourage them to do so, when people have deadlines to meet, those collaborations can't be sustained. Another issue is that we've been in competition for funding with a lot of economically crucial projects and so basic research has not grown as fast as was envisioned when I was hired. We're just starting to grow a little bit.

TR: How well is the high-tech industry doing in carrying out basic research? Is it achieving the right balance of providing for fundamental science while watching out for the bottom line?

WILLIAMS: In general, no. In today's viciously competitive environment, any high-tech company can go bankrupt within three years—or considerably less with the introduction of Internet time. It's very difficult to pay attention to the long term, which for the board of directors of some companies is the quarter after next. Even in corporate research labs, the pressure to get better aligned with product divisions, shorten research and development cycles, and fight day-to-day fires has collapsed the view of most managers and researchers to just a few years out.

TR: What does that mean for the computer industry?

WILLIAMS: I think that having a strong basic research component in a corporate laboratory is becoming a strategic advantage. This is especially the case for the high-tech companies that depend on advances in electronics. There will be a huge economic reward for the companies and countries that are successful in harnessing nanometer-scale structures and quantum phenomena for computation, communication and measurement applications. These are all still at the level of basic research, but they will be the foundations of technology long before I am ready to retire. Companies that are not keeping up with the developments will not be able to catch up later. The Fortune 100 will look much different in ten years than it does now, and a significant differentiator will be investments in basic research.

TR: Let's talk about the future of computing more specifically. You often refer to the limits of silicon-based computing. What are those limits?

WILLIAMS: There are two very different issues facing the semiconductor industry over the next decade. One is economic. The cost of building factories to fabricate each new generation of silicon chip has been increasing by a factor of about two every three years. A $10 billion fabrication plant, or "fab," is not far off. By 2010 a fab is likely to cost $30 billion. The second issue, which is one of the main reasons for the first, is that silicon-based transistors are starting to experience some fundamental physics and materials limitations as they get smaller and smaller. For example, the number of electrons utilized to switch a field effect transistor—the mainstay of today's computers—on and off is getting down into the hundreds, and as that gets much lower there will be severe problems with statistical fluctuations that could act to randomly turn it on and off. There are also the issues associated with the physics of traditional lithography [the use of light to etch patterns on silicon chips], such as how to accurately position wafers with a

precision of a few nanometers. Each of these problems has a technological fix that can squeeze out one or two more generations of shrinkage, but the fact that so many issues now have to be addressed simultaneously is nearly overwhelming.

TR: Will silicon-based technology suddenly hit a wall?

WILLIAMS: From the physics standpoint, there are no reasons why the industry can't get down to devices as small as 50 nanometers. But the problem is that getting there is becoming more and more challenging and more and more expensive. Rather than try to play the game, many companies will make an economic decision that they're not going to make state-of-the-art chips. I've been preaching this for some time, and even I'm surprised at how fast this is happening. National Semiconductor—here's a company with semiconductor right in its name—is not going to make next-generation microprocessors anymore. In fact, Hewlett-Packard announced recently that it will have its advanced processors built in a foundry (foundries are fabs that produce devices on a contract basis). Eventually there will be one or two fabs in the world building devices at the state of the art, and those fabs will probably be financed in large part by governments. Which means it probably won't happen in the United States.

TR: And at this rate, how long will that take?

WILLIAMS: My guess is that it will be before 2012. It's a big game of chicken. Who's willing to spend the money for a new fab?

TR: How will the rapidly rising production costs, and the subsequent effect of companies exiting manufacturing, affect microelectronics?

WILLIAMS: The prices for the items we are buying today will not go up substantially, but we will not see the dramatic improvements in performance and decreases in cost for silicon-based devices that we have seen in the past. And the fact that so many big companies are getting out of silicon process research will definitely hurt innovation in microelectronics for a while. However, this is also going to open the door for a lot of small-scale entrepreneurs and inventors looking to create entirely new electronic devices and fabrication processes. I think the next decade will provide one of the greatest explosions of creativity we have seen since the invention of the transistor.

TR: You have predicted that, at the current rate of shrinkage, silicon-based devices will start to reach fundamental limits around 2010. In terms of finding and developing new technologies to replace silicon, it's really not that far in the future, is it?

WILLIAMS: It's frighteningly close. There is not yet a definite heir to silicon technology. To have a new technology ready by then, we have to be working hard right now. At HP, we have what we think is a pretty good candidate, but I think that technology and the future economics of this country would be a lot better off if there were more than one heir, if there were several groups with unique ideas competing. There are a few good ideas out there, but not enough.

TR: I'm surprised that there are not more, given what's at stake.

WILLIAMS: A lot of the research is at the level of discrete devices. But there's very little architectural-scale work going on. Instead of looking at discrete basic units, we're looking at the function of an entire circuit.

TR: Rather than trying to make things at a nanometer scale, and then worry about how you might be able to use them, you already have in mind...

WILLIAMS: A potential overall structure. Most of the people who are working in this area are essentially trying to figure out how to make a molecular analogue of an existing electronic device; then they're hoping they'll figure out how to connect all these things to make a circuit or a system. People are essentially working hard to make a single brick and hoping that once they make it they can figure out how to build something out of it. On the other hand, we have the architectural drawing of the entire building, and we're looking for the best materials to construct that building.

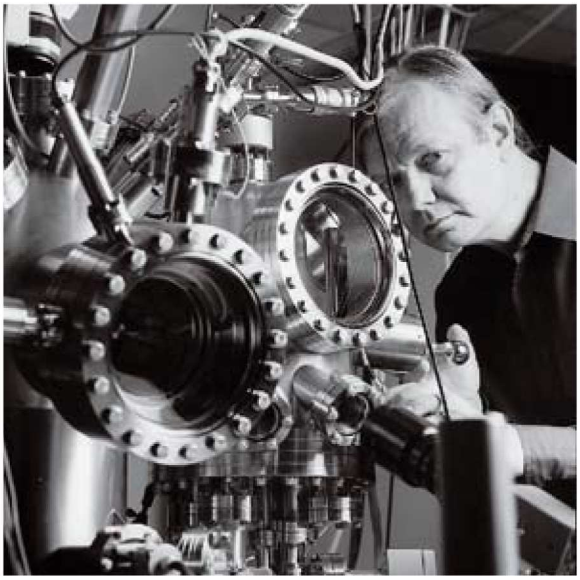
TR: Your ambition is to use this blueprint to build an entirely new type of computer, one fabricated using chemistry rather than lithography, isn't it?
WILLIAMS: Our goal is to manufacture circuits in simple chemical fume hoods using beakers and normal chemical procedures. Instead of making incredibly complex and perfect devices that require very expensive factories, we would make devices that are actually very simple and prone to manufacturing error. They would be extraordinarily inexpensive to make, and most of the economic value would come in their programming.

TR: It seems slightly counterintuitive that the way to make microelectronics even smaller and more powerful is to allow them to be defective.
WILLIAMS: A year ago we published a paper in *Science* in which we talk about what is going to be required to make a computer using chemical assembly. The answer was that you need to have a computing architecture that would allow the systems to have a lot of manufacturing defects, a lot of mistakes. We call that architecture defect-tolerant. We discussed an example of a computer that has been built here at Hewlett-Packard called Teramac. This is our computer archetype; we think that in the future things that are based on molecular-scale or nanometer-scale objects are going to have to have as part of their organizing principles these defect-tolerant designs because it's going to be impossible to make such small things perfectly.

"Our goal is to manufacture circuits in simple chemical fume hoods using beakers and normal chemical procedures."

TR: Tell us a little about the origins of your interest in Teramac.
WILLIAMS: James Heath, a UCLA chemistry professor, and I spent at least a year and a half studying it before we were ready to build anything. We were having a series of discussions with a computer architect at HP, Philip Kuekes, about defect tolerance, and Phil started talking to us about this computer that he had helped build. They had decided to build it from imperfect or defective silicon components, because those would be much cheaper, and just deal with whatever problems that came up by using clever software.

TR: In other words, you pay for a material's perfection.
WILLIAMS: Absolutely. Perfection costs a lot of money. And as you get more and more complex, the cost of perfection gets higher and higher. That's the main reason why the cost of fabs is increasing exponentially. What we're saying is that if we can make things that are imperfect but still work perfectly then we can build them a lot more cheaply.



TR: How do you make something that is imperfect work perfectly?
WILLIAMS: Teramac has an architecture that relies on very regular structures called crossbars, which allows you to connect any input with any output. If any particular switch or wire in the system is defective, you can route around it. You can avoid the problems. It turned out that Teramac had a huge bonus. Not only is it capable of compensating for manufacturing mistakes, but Teramac could also be programmed very rapidly and it executed those programs with blinding speed because it had this huge communications bandwidth.

TR: As constructed, Teramac uses silicon chips, albeit defective ones. But your interest is in using this architecture to build a computer using chemical processes. Why is it so promising for that application?
WILLIAMS: Teramac was built as a tool to demonstrate the utility of defect tolerance for building complex systems more cheaply. Even though it was a success, a desktop Teramac is not yet economically viable. It may be that Teramac-like architectures will help to extend silicon integrated circuits a generation or so by making fabs cheaper to build, but we see the huge potential for this architecture in chemical manufacture of integrated circuits. Assembling devices and ordering them by chemical means will be an inherently error-prone process. However, we now have proof that a highly defective system can operate perfectly.

TR: This actual architecture could provide an actual way to do computing?
WILLIAMS: It's real. The hardware was built, tested and programmed. The concepts are very well understood and very robust. Now the second stage of all this is to see if we can use the ideas coming out of basic research in nanotechnology—the ideas of self-assembly, constructing little regular units using chemical procedures—to actually make something that would be useful. Our *Science* paper this July is, we believe, the first major step in that direction in that we demonstrate that molecular electronic switching is possible.

TR: What's next?
WILLIAMS: Within two years, we hope to assemble chemically an operational 16-bit memory that fits in a square 100 nanometers on a side. Today, one bit in a silicon memory is much larger than a square micrometer. So, we're looking for a scaleup of at least three orders of magnitude in memory density. Our longer-term goal, frankly, is to build an entire computer using nothing but chemical processes. That particular goal is 10 years from now if everything goes well, and even then we'll be making fairly simple circuits. But it's got to start someplace. ◊

SM

The Investment Banker of Choice for Leading Computer Systems Companies Worldwide

$810,000,000
SEQUENT
has agreed to be acquired by
IBM
Pending

N.D.
FUJITSU
Fujitsu Limited and Siemens AG have agreed to establish a joint-venture company
Fujitsu Siemens Computers
June 17, 1999

$9,600,000,000
COMPAQ
has acquired
Digital Equipment Corporation
June 11, 1998

DELL
$500,000,000
Senior Notes and Debentures
April 22, 1998

IBM
$700,000,000
Debentures
January 6, 1998
$1,000,000,000
Senior Notes and Debentures
July 30, 1997

SiliconGraphics, Inc.
has acquired
ParaGraph International
September 30, 1997

$1,519,000,000
amdahl
has been acquired by
Fujitsu Limited
September 18, 1997

SiliconGraphics, Inc.
$234,000,000
Senior Convertible Notes
September 4, 1997

$2,727,000,000
COMPAQ
has merged with
Tandem Computers Incorporated
August 29, 1997

$356,000,000
AST RESEARCH INC.
has been acquired by
Samsung Electronics Co.
August 12, 1997

SEQUENT
$184,000,000
Common Stock
July 29, 1997

$1,180,000,000
HEWLETT PACKARD
has merged with
VeriFone, Inc.
June 25,1997

$130,000,000
FUJITSU
has acquired
Nexion
a division of
Ascom Holding A.G.
June 9, 1997

Data General
$212,750,000
*Convertible Subordinated Notes**
May 15, 1997

EMC²
EMC Corporation
$450,000,000
*Convertible Notes**
March 6, 1997

Apple Computer, Inc.
$661,250,000
6% Convertible Subordinated Notes
June 4, 1996

$145,000,000
amdahl
has acquired
Trecom Business Systems Inc.
April 23, 1996

HEWLETT PACKARD
$200,000,000
6¼% Senior Notes due 1999
April 18, 1996

$695,100,000
IBM
has acquired
Tivoli Systems, Inc.
March 4, 1996

$368,200,000
COMPAQ
has acquired
NetWorth Corporation
December 8, 1995

MORGAN STANLEY DEAN WITTER

*These Securities were sold pursuant to Rule 144A under the Securities Act of 1933 and may not be offered or sold in the United States absent registration or an applicable exemption from the registration requirements.

This Is No Fish Story

When big fish Johnson & Johnson announced plans to swallow little fish Centocor in July, it was more than just a typical transaction in biotechnology's food chain. It marked, at least indirectly, the latest chapter in one of biotech's most intriguing and edifying shaggy-dog stories.

Centocor, based in Malvern, Pa., had always been one of those "coulda, shoulda" players in the biotech world. In the game early, well-capitalized and with good scientific talent, the company always seemed poised to join the first echelon of biotech startups. But it never quite made the ranks of the Amgens and Genentechs.

In August of 1998, Centocor received approval from the Food and Drug Administration (FDA) to market a product called Remicade for the treatment of Crohn's disease, a debilitating intestinal disorder. The company now seems well-positioned to win approval also to market the drug as a treatment for rheumatoid arthritis. If approved, Remicade would compete against Enbrel, a similar product for treating rheumatoid arthritis that is manufactured by Seattle-based Immunex and which won FDA approval last September.

Monoclonal antibodies and TNF were two of the sorriest chapters in biotech. Now they're changing arthritis treatment.

The testimonials that have rained down on these two drugs, especially in terms of the rheumatoid market, rate right up there on the Hosanna Scale. Analysts and physicians predicted a "potential blockbuster." One doctor was quoted in *The Wall Street Journal* as saying: "In my 25 years of doing studies of rheumatoid arthritis medications, I've never seen clinical data this good." Remicade figured as a key factor in Johnson & Johnson's decision to acquire Centocor.

Yet how many people remember where this success story began? The drugs took the Jerry Garcia route to the marketplace—and what a long, strange trip it's been. Remicade and Enbrel have their origins in two of the sorriest chapters of the early history of biotechnology: tumor necrosis factor and monoclonal antibodies.

In 1975, in work that later resulted in a Nobel prize, Cesar Milstein and Georges Kohler of Cambridge University demonstrated that the laboratory-induced fusion of an immortal cancer cell with an antibody-spewing B cell could create a hybridoma, a living antibody-producing machine. Because each B cell produces a unique antibody with a specific biological task, the resulting hybridoma cell churns out the same one-of-a-kind, or monoclonal, antibody molecules. Biotech startups like Centocor, which began operations in 1979, were formed to exploit the breakthrough.

Following a much-publicized early success in the treatment of a lymphoma case at Stanford University Medical Center, monoclonals made their debut as the industry's magic bullet du jour. Optimism so outdistanced discipline that one academic scientist told me at a meeting several years ago that monoclonals that had not even been properly characterized in the lab were being used in clinical trials—trials that failed, one after another. Too much promise and not enough rigor doomed monoclonals to an unkind fate.

Meanwhile, back in 1975 again, Elizabeth Carswell, Lloyd Old and their colleagues at Sloan-Kettering Research Institute in New York reported the discovery of a molecule that caused tumors to melt away in mice. Dubbed tumor necrosis factor, or TNF, the molecule incited the usual riot among investors and the usual hype from companies. In short order, the TNF gene was cloned, the protein mass-produced and an ugly truth unearthed: At doses humans could tolerate, patients derived no benefit whatsoever. By 1990, TNF had joined monoclonal antibodies in the pile of spent bullets in the war on cancer.

And now we arrive at one of the most interesting tensions in biotechnology: the always-yawning gap between pharmacological aspiration and biological reality. Although no one appreciated it in the early days, TNF is one of the body's baddest actors when it comes to inflammation. Only in the late 1980s (and only, it should be noted, out of pure academic interest) did researchers discover that rheumatoid arthritis arises from a cascade of inflammatory proteins that collect in the joints, among which perhaps the worst of the bunch is—you guessed it—TNF. Separate research established that Crohn's disease was also caused by an excess of the factor.

From that biological insight, it was a logical next step to suggest that a monoclonal antibody that neutralized TNF might short-circuit the ravages of rheumatoid arthritis and Crohn's disease. Though Centocor's earlier attempts to turn anti-TNF monoclonals into a viable drug to treat sepsis had failed, the company's experience positioned it perfectly to develop monoclonals against TNF to treat rheumatoid arthritis and Crohn's disease.

Henry Adams, in his autobiography *The Education of Henry Adams*, makes the wise point that any path that arrives at the destination is the right one. But it's hard to square that haphazard form of navigation and everything it implies—luck, happenstance, accident, misdirection and perseverance—with the linear and often unforgiving thinking that goes into business plans, revenue streams and burn rates. The TNF story is a reminder that, for every success like Remicade, there are an awful lot of little white crosses on the side of the road. ◊

CULTURE ZONE

HENRIK DRESCHER

VIEWPOINT | BY DANIEL AKST

Money Goes Downmarket

E-finance is faster, but people aren't any smarter

Once upon a time, rich people often bought even small things on credit, lest they sully themselves handling filthy lucre. They employed professional investment advisers to manage their money, which might be deployed in stocks, bonds or real estate. Should the need for a loan arise, one's personal banker arranged it. (Discreetly, of course.)

Nowadays that description might apply to the great bulk of middle-class Americans—except it's inadequate. When I go shopping, I pay with plastic, obtaining instant credit from merchants anywhere in the world, even though they've never heard of me. As to investing, no robber baron or trust-fund scion ever had more choices. With a toll-free telephone call or a few mouse clicks, I can put my money in an infinite variety of stocks, bonds, mortgage-backed securities, real estate investment trusts, money market accounts, options and futures, to say nothing of professionally managed mutual funds. The assets held by these investment pools are scattered from New York to Nepal.

If I need a loan, I can write myself a check. If I want to buy a house, I can shop for a mortgage electronically. Rather than limiting myself to a single local bank (the one that knew my father and his father), I can scour the country for the lowest possible rates. Mortgages come in more flavors than gelato. Variable-rate loans, which require frequent recalculation, were made possible by the spread of cheap computing power. The same is true for money market funds. As to credit cards, modern telecommunications and information technology paved the way.

In a single generation, technology has remade the financial landscape. The net effect: a remarkable democratization of consumer finance and investing. As in other walks of life, technology is the leveler, giving the average person the ability to do what once required wealth, specialized flunkies and the greatest

luxury of all—time.

"As much as anything, computer technology made the money revolution possible," argues Joseph Nocera in his lively history of postwar consumer finance, *A Piece of the Action: How the Middle Class Joined the Money Class.* "Computers are the hidden spine of every modern financial device."

But the marriage of technology and finance has proved to be, like most marriages, an affiliation with an uncomfortable side. The technology that has made it easy for me to buy anything, anywhere, anytime has created its own difficulties. For one thing, it's made it easy for people to get into trouble, running faster and faster on the treadmill of getting and spending until they reach the point of financial exhaustion. The corollary is that bankruptcies have soared, and going bust has lost the stigma it had a couple of generations ago.

Then there's the woman who stole my wife's identity. She started by stealing her wallet. Despite my wife's prompt notifications, the thief used the credit cards, passed a number of checks and adopted her victim's name as an alias. For a long time thereafter, merchants required elaborate proof to accept my wife's checks, and several years after the initial theft, she was rejected for phone service by a new provider because, the company said, she had a large outstanding balance. Generated, of course, by the crook.

This annoyance is more or less personal to us. But some dangers created by the technological revolution affect us all. Massive, cheap computing power has made possible a volume of securities trading heretofore unimaginable, while fostering a profusion of financial instruments so abstruse only savants understand them. These "derivatives," whose value derives from some underlying asset, often were created to control risk, but in the aggregate they add a huge, unknowable level of uncertainty to the financial markets. Edward Chancellor, in his recent *Devil Take the Hindmost: A History of Financial Speculation,* notes that "by the end of 1996, the size of outstanding derivatives contracts was estimated at around $50 trillion, although since most of the derivatives trade was conducted away from the exchanges in the over-the-counter market, no one was sure of the figure."

Equally troubling, the spread of Internet stock trading has made it possible for every Tom, Dick and Mary to become a day-trader. Using the Internet, investors can buy and sell shares for commissions in some cases 99 percent less than those charged in ye olde days of full-service brokers (in, say, 1992). At little effort or expense, they can draw on company announcements, Securities and Exchange Commission filings, press reports, analyst recommendations and, of course, the opinions of other online aficionados.

What these wired do-it-yourselfers generally cannot do is beat the market. Researchers at the University of California, Davis, report that individual investors "pay a tremendous performance penalty for active trading." In a study of 66,465 households with accounts at a large discount brokerage firm from 1991 to 1996, management professor Terrance Odean and finance professor Brad M. Barber found that the most frequent traders underperformed the market by a stunning 6.5 percentage points. "Our central message," the professors wrote, "is that trading is hazardous to your wealth."

One reason may be the propensity of investors to sell the wrong stock. In a study of 10,000 brokerage accounts, Odean writes, "I find the surprising result that, on average, the stocks they purchase actually underperform those they sell. This is the case even when trading is not apparently motivated by liquidity demands, tax-loss selling, portfolio rebalancing, or a move to lower-risk securities."

This Wrong-Way Corrigan approach to trading persists despite—or perhaps because of—the growing volume of

The technology that makes it easy to buy anything, anywhere, anytime has created its own difficulties.

information available to private investors. Novices report being paralyzed by the vast array of mutual funds from which to choose, equaled only, it seems, by the vast array of publishers and others who provide information about mutual funds. Consider the change this represents. Not long ago, the trick was simply getting information in the first place, but the age of information scarcity is long gone. Gaining information is already easier than figuring out which information to pay attention to, and the future promises such unprecedented informational abundance that we'll practically have to work just in order to avoid it. What will matter, in other words, is the quality of your filters.

Which brings us back to two dimensions of life in the previous era: expertise and personal service. Wealthy investors, for example, may hire personal data-editors or researchers, instead of bankers and brokers. Or they may hire well-educated assistants, the way people do in Hollywood, to administer their finances (if not their lives) using information technology. If knowledge is power, why not pay somebody to harness that power for you? (Of course, "agents," the perennially heralded smart software that will go out on the Internet and find us just the right pair of shoes based on our lifestyle and color preferences, may usurp this function, or provide it to those who can't afford an actual human being.)

The final scary aspect of the financial brave new world is the disappearance of money itself—at least in tangible form. Digital cash is right around the corner, potentially replacing the coin of the realm with "money" that exists only on "smart" cards, hard drives and other electronic media. Many of the implementations of digital cash now being discussed lack one of cash's primary characteristics—anonymity. Greenbacks let you buy anything without anyone knowing who you are, but most forms of digital cash would carry an indication of provenance, in some cases acting more like checks than dollar bills. Coupled with the extraordinary amount direct marketers seem to know about us, this potentially revolutionary change gives some of us the digital willies.

Only time will tell whether the main leveling effect of technology on money will be to make us all equally its slaves. TR

MIXED MEDIA

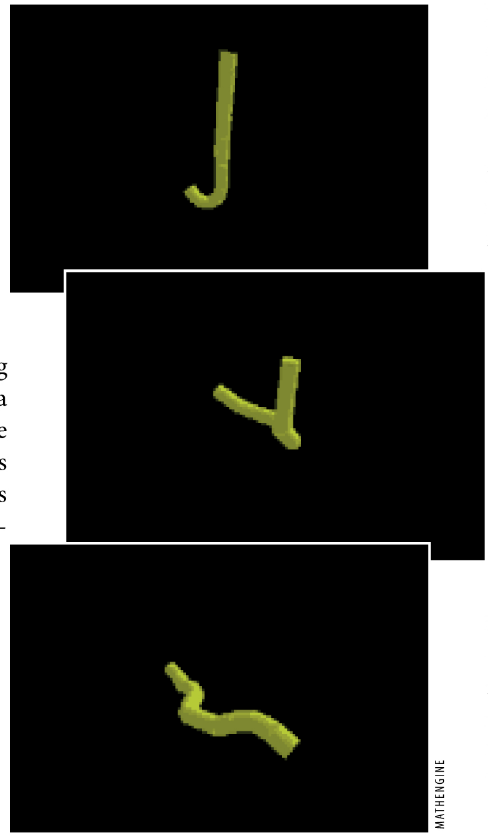
Kaboom! Video Games Get Physical

Physicists inject a dose of reality into screen simulations

FIRE UP MOST VIDEO GAMES AND you enter a parallel universe where the laws of physics do not apply. Trajectories, collisions, explosions all behave differently than they do here on Earth. While graphics resolution and sound quality have dramatically improved in recent years, the underlying physics have remained primitive.

That's about to change. In their continuing quest for greater realism, game makers are upgrading and designing new 3-D simulation games by injecting a heavy dose of real-world physics. "Game developers always need to find new things to innovate and for many today that means better physics," notes Chris Hecker, a technical developer at Definition Six, a Seattle-based game company who has organized talks on physics at developers' conventions.

With more computer power and proper skills, developers are able to design games in which the underlying properties of many game objects—not just a few—conform to the laws of physics. Weapons, bridges and vehicles need no longer follow scripted patterns.



MATHENGINE

The algorithms that animate this undulating rope bring truer motion to the videogame realm.

Instead, objects can be programmed with an underlying set of rules that let them fall, stack, slide and sink in an intuitive manner, displaying the variety we experience in everyday life. For players of motor racing, flight simulations, and all manner of action and shoot-em-up games, this means far more lifelike and unpredictable explosions, collapses and collisions. Game worlds will now be enhanced with rippling waves, pouring rain, sinewy smoke and flickering fires.

Thanks to enhanced game physics, players will be able to smash through windows, pick up manhole covers and feel the heft and weight of different weapons. They will experience massive explosions where particles and shrapnel spin wildly out of control, exerting a force on everything in their course of flight. This will be a vast improvement, developers say, over today's typical action game, in which an explosion may result in a static cartoon graphic that says "Kaboom."

Some predict that creating these complex, algorithm-driven, 3-D simulations will require an overhaul in the way games

WEB SITE

Calling All Idle Computers

WWW.DISTRIBUTED.NET

The Internet has changed the concept of the supercomputer: No longer a monolithic machine tucked away in a university or government lab, it can now comprise a network of ordinary computers working together on a single project. Distributed.net serves as the clearinghouse for information on such "distributed computing" efforts. The site seeks to promote this practice by developing client software and a network of users. The software, available for most major platforms, analyzes data when the client computer would otherwise be idle.

Distributed.net has sponsored several contests to break encryption codes, including the 56-bit Data Encryption Standard (DES) used by the federal government. In the most recent attempt, Distributed.net users teamed up with the Electronic Frontier Foundation to break a DES-encrypted message in less than 24 hours. A contest now under way seeks to crack the stronger 64-bit RC5 protocol. The nearly 200,000 users of Distributed.net can ally themselves with one of over 7,000 teams, competing to analyze the most data and eventually crack the code. Another project in the works will search for members of a class of numbers known as Optimum Golumb Rulers, which have applications ranging from radio astronomy to X-ray crystallography. You don't need a continuous Net connection to contribute your computer to these communal quests, just as long as you log on every day or so.

—Jeff Foust

are designed. Game companies may find they need to form teams of physics- and math-savvy programmers. Irving, Texas-based Motorsims, for example, has hired a PhD in vehicle collision and handling dynamics along with a former principal engineer in aerospace guidance from Boeing to work on its new racing games.

Another strategy is to license a physics game engine produced by one of several new companies, such as Telekinesys in Dublin and Ipion in Munich. One company—two-year-old MathEngine—employs 50 physicists, mathematicians and computer programmers. These experts, located at the company's headquarters in Oxford, England, and five other facilities around the world, work as a virtual team to create physics engines. Will Osborn, who studied theoretical physics at Cambridge University and now directs MathEngine's research group, explains his new profession's appeal: "Instead of wondering where my research funding is going to come from every year, I get to work on a whole range of physics—aerodynamics, rigid body dynamics, fluid dynamics, and graphic and rendering techniques."

MathEngine's physics engine is one of several tools sanctioned for the next generation Sony Playstation game console. The software enables developers to add complex physical behavior to real-time, 3-D environments without having to derive the complicated mathematics from scratch. By using it, game makers are able to add interactive and dynamic sequences in hours rather than days or weeks. Simple visual demos on the company Web site show animations of swirling leaves and other examples of complex physics that the MathEngine kit makes easy (www.mathengine.com/Product/demos.htm).

You'd think game developers would welcome these new tools with open arms. But in fact, some have mixed feelings. Ken Perlin, founder of New York's Improv Technologies and creator of a new "cartoon physics" tool for developers, says the key element for a successful game is that the characters are believable—which is not the same as being realistic. Computer game design has never been about modeling reality, insists Noah Falstein, founder of The Inspiracy, a game consulting firm in Greenbrae, Calif. Instead, he says, it has mostly been about creating illusions of reality: "Witness the popularity of the Star Wars Pod Racer games—George Lucas is a genius at creating a fantasy that 'feels right,' despite gross violations of physical laws."

But just as earlier advances in computing hardware ratcheted up game players' expectations for graphic precision and audio quality, the movement toward realistic physics has too much momentum to stop. "Now that the computational power of PCs and game machines is so much more advanced, the element of physics in every game is going to keep on increasing," says Michael Valdez, a game developer at Looking Glass Studios in Cambridge, Mass., who came to games via the study of aeronautics at MIT and work at NASA's Jet Propulsion Laboratory.

With the recent uproar over video game violence, of course, enhanced realism may not be exactly what society's doctors order. But the consumers of games will be the ones whose tastes prevail—and those consumers will probably develop a taste for the "new physics" just as soon as it comes online.

—Katherine Cavanaugh

DVD

Can DVD Catch Up to Its Promise?

Capturing a hot market and exploiting technological promise are two different things. Take the DVD. The digital video (oh, all right, versatile) disc player is one of the fastest-selling consumer electronics introductions ever, with more than 2.5 million units shipped in the United States since March 1997. But for all their commercial fizz, DVDs have barely touched the interactive possibilities of the medium for presenting movies. Wide-screen format, alternate takes, cast filmographies, even directors' narrations are all well and good—but these bonus features have been available on 12-inch laser discs since the antediluvian '80s.

INTERACTUAL TECHNOLOGIES

Supercharged "Blast": Peering behind the silver screen

Now, the DVD may be beginning to live up to its potential—though in conjunction with the PC rather than the TV. A good example was the first live DVD online event, earlier this year, for director John Frankenheimer's film, "Ronin." Frankenheimer chatted from the movie's Web site, referring to outtakes and other hidden material triggered to play off each visitor's DVD—but only for those on a Windows PC equipped with a DVD-ROM player. (The event is archived at www.mgm.com/dvd/ronin for replay with the disc).

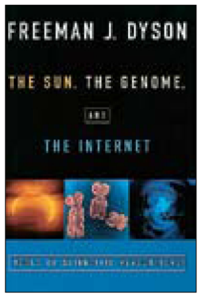
"There's so much more content possible for DVD movies with a PC and the Internet," explains Tom Collart, CEO of InterActual Technologies in Mountain View, Calif. Collart's company publishes the "PCFriendly" software that manages the content on the "Ronin" DVD. He cites such possibilities as always-up-to-date filmographies and early versions of scripts, downloaded from a movie's Web site. PCFriendly already allows movie buffs with a PC to view the shooting script for "Rush Hour" (and other New Line releases) and link to the corresponding scene on the disc.

As DVDs become standard on desktop and laptop machines, PCs with higher resolution displays will far outnumber DVD players attached to televisions. Powerful PCs and Macintoshes—and soon-to-appear DVD-playing set-top boxes for cable-connected TVs—should make greater interactivity commonplace. Now that the potential of the medium has begun to be tapped, the question remains: Which major film director will be first to use the DVD's powers to the maximum? Who will create the first truly interactive movie, with, say, multiple plot lines and endings? "The obstacle isn't technical," says Collart, who is in the midst of discussions with almost all the Hollywood studios for use of his software. "No successful feature film director is going to risk a career by being first with interactive story-telling on DVD." **—Steve Ditlea**

PAGES | BY WADE ROUSH

Revolutionary Visions

THE SUN, THE GENOME, AND THE INTERNET: Tools of Scientific Revolutions
by Freeman Dyson
Oxford University Press, 124 pp., $22



DURING MY TEENAGE YEARS, which precisely spanned Ronald Reagan's presidency, reading Jonathan Schell's morbid, spellbinding antinuclear tract *The Fate of the Earth* fueled my fears of nuclear war. Freeman Dyson's *Weapons and Hope* provided a needed antidote. Dyson showed that it was possible to be passionate about nuclear weapons without being desperate; pro-disarmament without being unrealistic. It's good to see that Dyson's passion and optimism haven't flagged. In *The Sun, the Genome, and the Internet*, he displays a similar childlike enthusiasm about the possibilities for humanity's future, informed and tempered by a physicist's understanding of the real world.

The book, which expands a series of lectures Dyson gave at the New York Public Library in 1997, is his attempt at fin-de-siecle futurology. While he admits that "experts, when they try to predict the future, are usually wrong," he argues that models of the future, like models in science, can lead to at least partial understanding.

In Dyson's vision, the greatest "paradigm shifts" in 21st-century life will be wrought by advances in three specific technologies: solar energy, genetic engineering and computer networks. When improvements in photovoltaic cells or biomass power generation make sunlight a cheaper source of electricity than fossil fuels, the multitudinous rural poor will enjoy a big improvement in living standards, he predicts. Using their newly available electricity and low-orbit communications satellites, villages will be able to plug into the Internet, ending their cultural isolation and giving them new access to commerce and education.

Biotechnology enters the picture as the key to new high-efficiency energy crops, in which photosynthesis will be souped up to convert as much as 10 percent of the energy in sunlight into hydrocarbon fuel. Dyson envisions villages nestled within "permanent forests of trees that convert sunlight into liquid fuel and deliver the fuel directly through their roots to a network of underground pipelines." By the late 21st or early 22nd centuries, Dyson speculates, biotech products such as warm-blooded plants that grow their own greenhouses will enable humanity to create Earth-like environments on other worlds, beginning a vast migration to Mars, the asteroids, or the comets of the Kuiper Belt beyond Neptune.

It's been a long time since a respectable scientist voiced such grand aspirations in print, making Dyson's book refreshing and thought-provoking, if a bit farfetched. As Dyson writes, "It is not important that we correctly identify the road before we reach it. The purpose of this book is to encourage us to search for it."

Too Much of a Good Thing?

THE CONTROL REVOLUTION:
How the Internet Is Putting Individuals in Charge and Changing the World We Know
by Andrew L. Shapiro
PublicAffairs, 286 pp., $25

If a media sage like marshall McLuhan had come along in 1952, six years into the television era, to warn Americans how TV would affect family life, cultural values and the political process, they might have thought twice about abandoning this powerful medium to commercial interests. Today the Internet revolution is six years old, having gotten under way in earnest when the federal government lifted restrictions against the commercial use of the network in 1993. Andrew Shapiro's *The Control Revolution,* which takes a sober look at the social and political upheavals already visible as we leap into the wired world, may help prevent history from repeating itself.

The first few chapters catalog the Net's benefits. It provides a wealth of information options, makes it easy to filter and personalize the news we receive, eliminates costly middlemen from many commercial transactions, creates "the potential for everyone to be a publisher" and fosters an electronic direct democracy that can guide, and sometimes rein in, representative government.

Like television, though, the Net can be too much of a good thing, and Shapiro's unbiased exploration of this fact is what separates his work from the panoply of airport-bookstore hardcovers hyping get-rich-quick schemes in cyberspace. For one thing, software that filters the information we receive according to our pre-established tastes could yield a more fragmented society, in which we can track the values of our mutual funds by the minute but are rarely exposed to diverse viewpoints on issues affecting the commonweal. "What we might unwittingly bring about," Shapiro writes, "is nothing less than the privatization of experience."

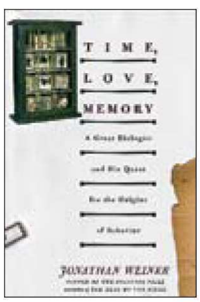
"Push-button politics" represents the opposite danger. Increasingly, politicians feel beholden to instant opinion polls enabled by electronic media, and special-interest groups exploit the Internet to influence legislative and judicial proceedings. "If we can use technology to express our governmental preferences directly, why do we need legislators and bureaucrats at all?" Shapiro taunts. The obvious answer: The Founding Fathers intentionally put matters of law and policy into the hands of professional leaders, freeing the rest of us from the burden of deliberating on critical issues. "How could we possibly hope to master, over the course of a few evenings or a weekend, the history and details of a thousand-page budget bill?" writes Shapiro. "Why, frankly, would we want to?"

A thoughtful concluding section, "Balance," explores how

to "make the [Internet] revolution turn out right." Shapiro suggests that isolationism, for example, could be combated by creating a kind of electronic Hyde Park where low-visibility community groups, activists and artists would be able to "confront their fellow citizens" and restore a sense of unpredictability to online life. This appealing idea, and many more, make *The Control Revolution* a must-read for anyone interested in computers and culture.

The Cosmos in Our Heads

Time, Love, Memory:
A Great Biologist and His Quest for the Origins of Behavior
by Jonathan Weiner
Alfred A. Knopf, 300 pp., $27.50



Overexuberant press accounts of recent genetic linkage studies have led the public to believe that there is a "gay gene," a "gene for novelty-seeking," a "gene for happiness" and a gene for just about every other human idiosyncrasy. But to biologists who study even comparatively simple animals such as the fruit fly, it's laughable to speak of any single gene as determining behavior. *Time, Love, Memory*, Jonathan Weiner's first book since his Pulitzer Prize-winning *The Beak of the Finch*, is about a little-known Caltech geneticist named Seymour Benzer and his innovative experiments on bacteria-eating phage and *Drosophila* fruit flies. By tracing four decades of Benzer's painstaking work, Weiner shows that biology's picture of the relationship between genes and behavior is growing more baroque, not less.

A year after James Watson and Francis Crick solved the structure of DNA in 1953, Benzer proved that genes are physical entities that can be dissected and put back together, a fact that allowed him to draw the first detailed map of a gene's interior. This helped Crick and colleague Sydney Brenner to decipher how DNA's four nucleotides (A, C, G and T) encode amino acids and proteins, and to show that most mutations—whether in phage, flies, or philosophers—are due to simple typographical errors in this code.

This was the thread, Benzer realized, that might allow biologists to unravel the genetic differences behind "the innumerable quirks of our bodies and minds," as Weiner puts it. He began to study fly strains with aberrant circadian cycles. His lab showed in 1967 that three such strains all had mutations in the same region of their X chromosomes, implying that the region harbors a "clock" gene. Named *period*, this gene has since been found in organisms from mice to men, and is famous among biologists as one of the first to be associated with a specific behavior.

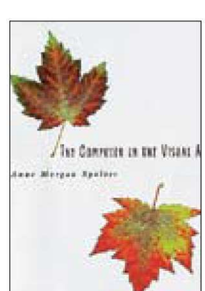
But that was only the beginning of the story. *Period* and another gene called *timeless* turn out to encode proteins with the ability to switch off their own production once they reach a certain concentration inside brain cells. Production is switched back on by other proteins, and all of these proteins mesh with still more genes and proteins in what Weiner poetically calls "a kind of orrery in the heart of every one of our cells...a model of the cosmos inside our heads that cycles whether we are in or out of the sun."

Every new fruit fly mutation seems to reveal a new gear in the orrery. Even the simplest behaviors arise from genetic interactions so numerous and interlaced that scientists like Benzer are only beginning to understand them. Weiner's book is the most deft, level-headed explanation of this fact I've seen. It's enough to make one believe in a gene for good writing.

Every Photo A Painting

Computers in the Visual Arts
by Anne Morgan Spalter
Addison-Wesley, 500 pp., $45

The spectacular space battles seen in *Star Wars*, released in 1977, were created using miniatures, blue screens and optical compositing on plain old celluloid. The film's computer graphics crew? Four. Behind *Star Wars: Episode I—The Phantom Menace*, by contrast, was an army of hundreds of digital effects artists. For *Episode II*, director George Lucas has said, the live-action scenes will be shot using digital movie cameras, leaving not a single scrap of film on the cutting-room floor.



Bits and bytes, in other words, are rapidly replacing crystals of silver on paper or film as the dominant storage medium for two-dimensional images. Because bits are so malleable, video artists can give visual form to an astonishing new range of ideas.

For most people, unfortunately, the process of creating and manipulating digital images remains as arcane as the alchemy of the photographic darkroom. In her new college textbook *Computers in the Visual Arts,* Anne Morgan Spalter, an artist in residence with Brown University's Computer Graphics Group, has set out to demystify the subject. The result is not so much a textbook as a friendly, comprehensive, mostly nontechnical introduction to the tools and techniques used by digital artists. Anyone who has marveled at *Toy Story* or *A Bug's Life* will find it a stimulating tour.

Spalter reveals, for example, that "a pixel is *not* a little square." It is actually a list of numbers, some for the coordinates of a point on the computer screen and others for the brightness of red, green and blue phosphors at that point. Local or global changes to a digital image can be made simply by performing addition, subtraction or other mathematical operations on these numbers. This, in fact, is all that high-priced photo-editing programs like Adobe Photoshop really do, Spalter notes.

While she explains the workings of photoediting software in some detail, Spalter never loses sight of the history, theory and implications of the rise of the bit in visual discourse. "Our concept of visual truth may come full circle as new technologies come into play," she writes. In the 16th century, Europeans saw new linear-perspective paintings as miraculously realistic; 19th-century photography increased this realism by storing actual light patterns. "But in a postphotographic world, the strength of that connection [to reality] is again uncertain," Spalter concludes sagely. "Every photograph becomes a painting." ◊

MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

CAREERS AND CLASSIFIEDS

Technology Review Classifieds and Recruitment Advertising

Display Recruitment Advertising

For rates and information contact:

Paul Gillespie Tel: 617-253-8229
Fax: 617-258-5850

Classified Advertising

RATES: $55 per line, 3-line minimum.
(One line equals approx. 50 characters.)
All classified line ads must be pre-paid.
To submit a classified ad, mail, fax, or e-mail text and billing information to:

Technology Review
Attn: Tanya Lauda
MIT's Building W59-200
77 Massachusetts Avenue
Cambridge, MA 02139
Tel: 617-253-1421; Fax: 617-258-5850
advertising@techreview.com


SCIENCE MUSEUM/SCIENCE & SOCIETY PICTURE LIBRARY

Got a Light?

John Walker brought the power of Prometheus to our fingertips

UNLESS YOU'VE BEEN SHIPWRECKED OR YOU'RE AN EXTREMELY ill-prepared camper, you've probably never had to make a fire without a device for instant ignition. But 200 years ago it was a whole different story: Those in need of warmth, light or a cooking flame had to nurse embers from fire to fire or coax sparks from a flint and hope the tinder caught. An English chemist and druggist named John Walker changed all that with his invention of "Sulphurata Hyperoxygenata Fricts," the ancestors of today's everyday match.

Walker's curiosity was sparked by an 1826 lab accident. He had been mixing a batch of combustible chemicals with a wooden stick and inadvertently scraped the stick on the hearth—the tip flared and the wood caught fire. With further experimentation, he hit on the right recipe for ignition, a blend of potassium chlorate, antimony sulfide and gum, and dipped narrow cardboard stems in the mixture. When drawn through a folded piece of sandpaper, the coated tip would sputter and light.

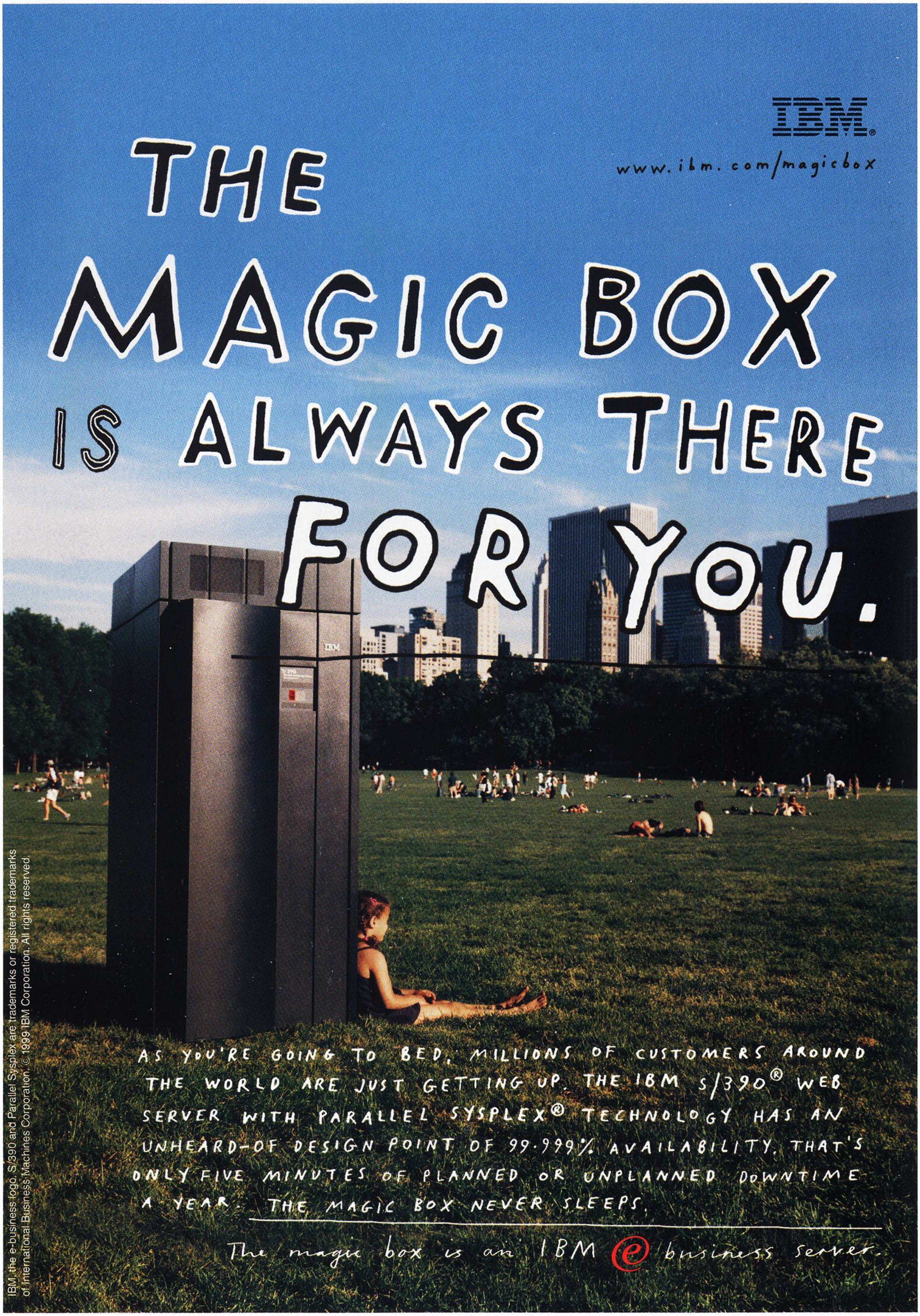
On April 7, 1827, Walker sold 100 of the new matches in a tin "pillar box" for one shilling two pence. It was his first recorded sale, marked in the ledger above on the line indicated by the white-and-red plastic arrow. A few months later, Walker changed the name of his invention to the more manageable "friction lights," and began using wooden splints—cut by hand by local paupers and schoolboys—in place of cardboard stems.

Technology Review welcomes suggestions from readers for Trailing Edge. If yours is selected, you will win a year's subscription to *TR*. This issue's winner is Kyle Jones, a freelance history-of-technology writer from the U.K. Send a few paragraphs to: Trailing Edge, *Technology Review*, MIT Building W59-200, Cambridge, MA 02139; or e-mail: trailingedge@techreview.com.

As sales increased, Walker's lights radiated from his store in Stockton, England, and eventually reached the hands of pioneering chemist and physicist Michael Faraday. Faraday implored Walker to patent the device, but the inventor was more philanthropist than entrepreneur, insisting: "I doubt not it will be a benefit to the public, so let them have it." With no patent protection, and with Faraday publicizing the invention in writings and lectures, others began to manufacture versions of Walker's lights.

Walker ceased making matches as early as 1830, when a copycat product called the "Lucifer" began gaining popularity. Since his time, match manufacturers have changed the tip's chemical composition to improve safety and brought back cardboard stems for matchbooks. But all in all, the friction match remains much the same as the first light Walker struck. ◊

Technology Review (ISSN 0040-1692), Reg. U.S. Patent Office, is published six times each year (January/February, March/April, May/June, July/August, September/October, and November/December) by the Association of Alumni and Alumnae of the Massachusetts Institute of Technology. Entire contents ©1999. The editors seek diverse views, and authors' opinions do not represent the official policies of their institutions or those of MIT. Printed by Lane Press, S. Burlington, VT. Periodicals postage paid at Boston, MA, and additional mailing offices. Postmaster: send address changes to *Technology Review*, MIT, Building W59, 201 Vassar St., Cambridge, MA 02139, or e-mail to address@techreview.com. Basic subscription rates: $30 per year, Canada residents add $6, other foreign countries add $12. Printed in U.S.A.
ABC audited


IBM
www.ibm.com/magicbox
THE MAGIC BOX IS ALWAYS THERE FOR YOU.
AS YOU'RE GOING TO BED, MILLIONS OF CUSTOMERS AROUND THE WORLD ARE JUST GETTING UP. THE IBM S/390® WEB SERVER WITH PARALLEL SYSPLEX® TECHNOLOGY HAS AN UNHEARD-OF DESIGN POINT OF 99.999% AVAILABILITY. THAT'S ONLY FIVE MINUTES OF PLANNED OR UNPLANNED DOWNTIME A YEAR. THE MAGIC BOX NEVER SLEEPS.
The magic box is an IBM e business server.
IBM, the e-business logo, S/390 and Parallel Sysplex are trademarks or registered trademarks of International Business Machines Corporation. © 1999 IBM Corporation. All rights reserved.